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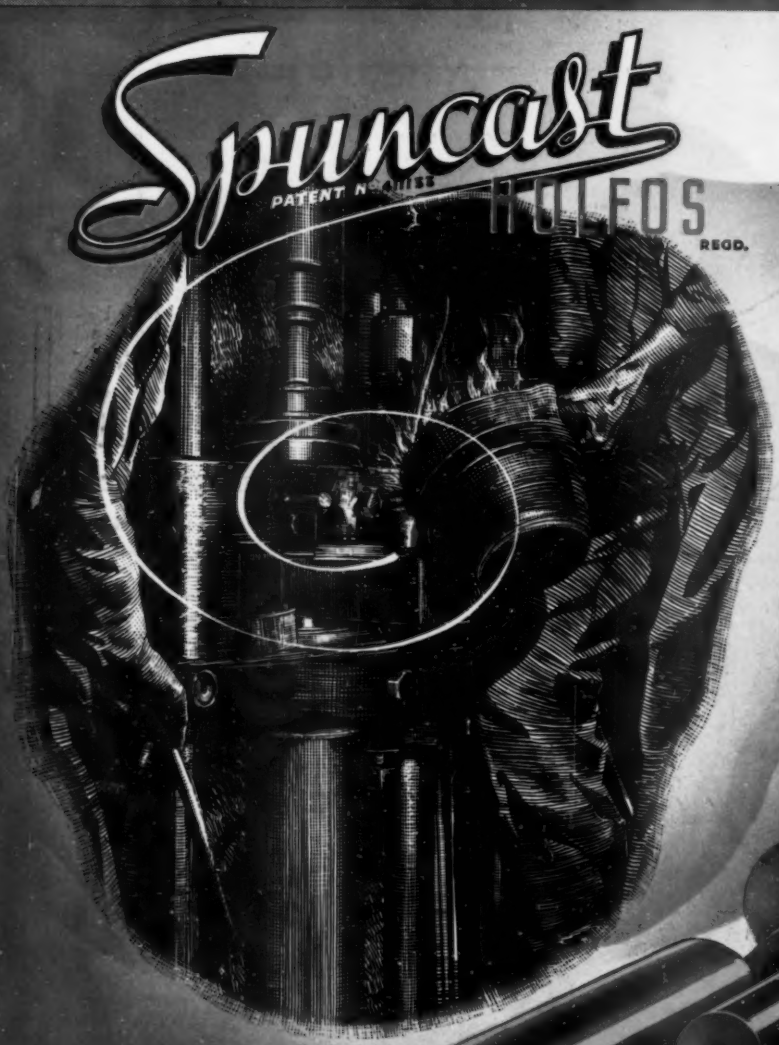

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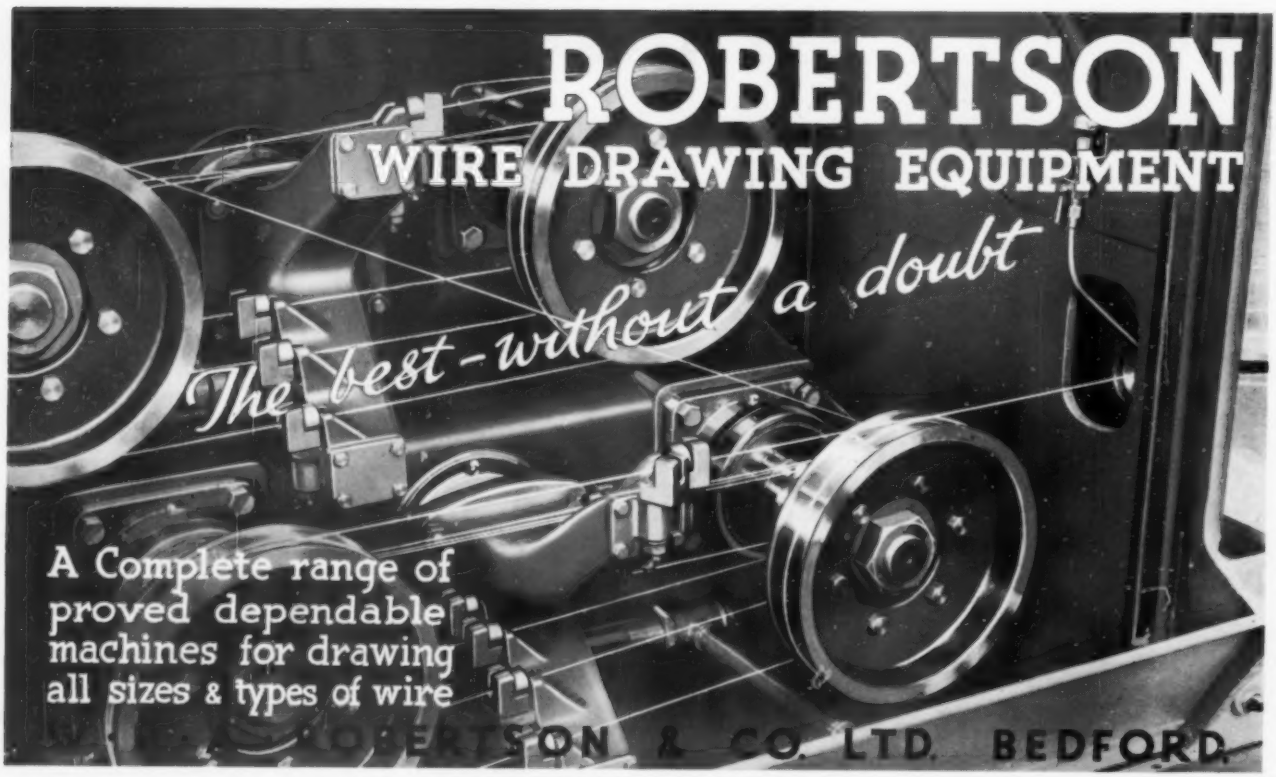
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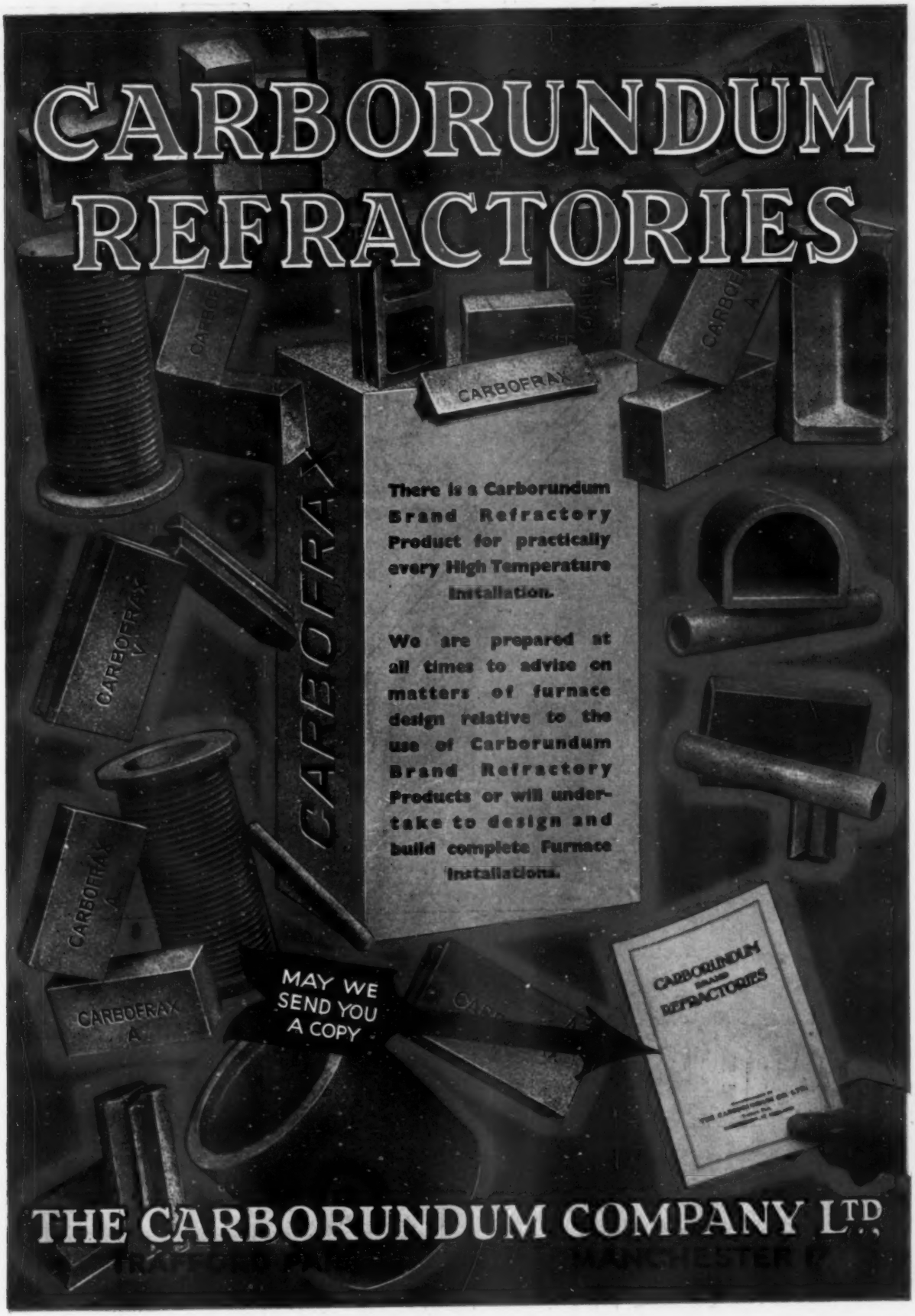
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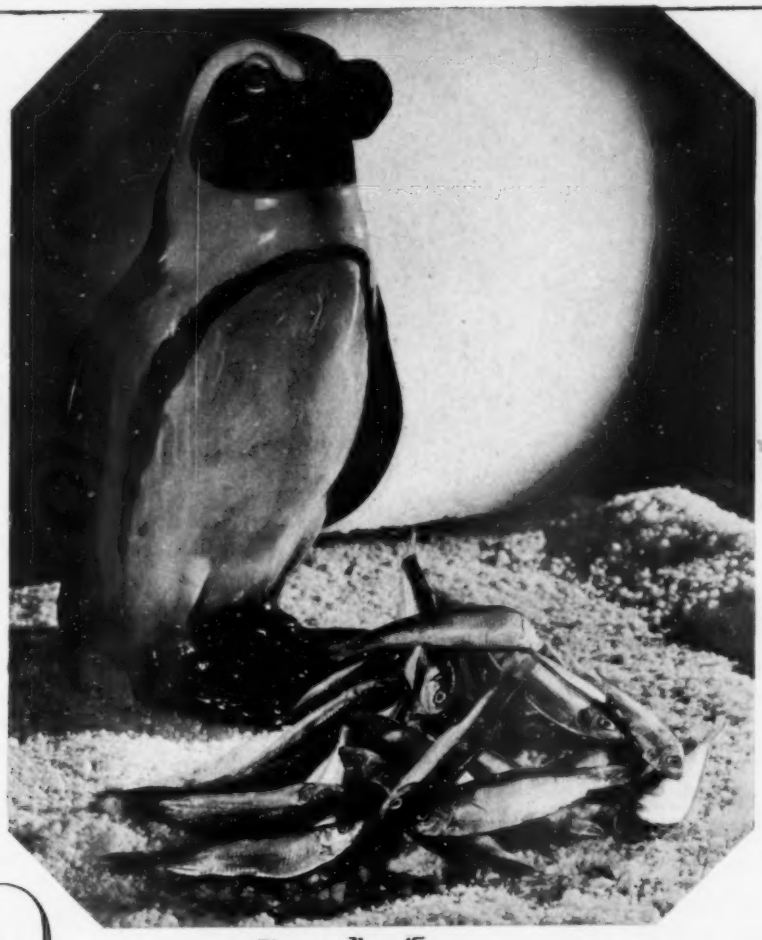

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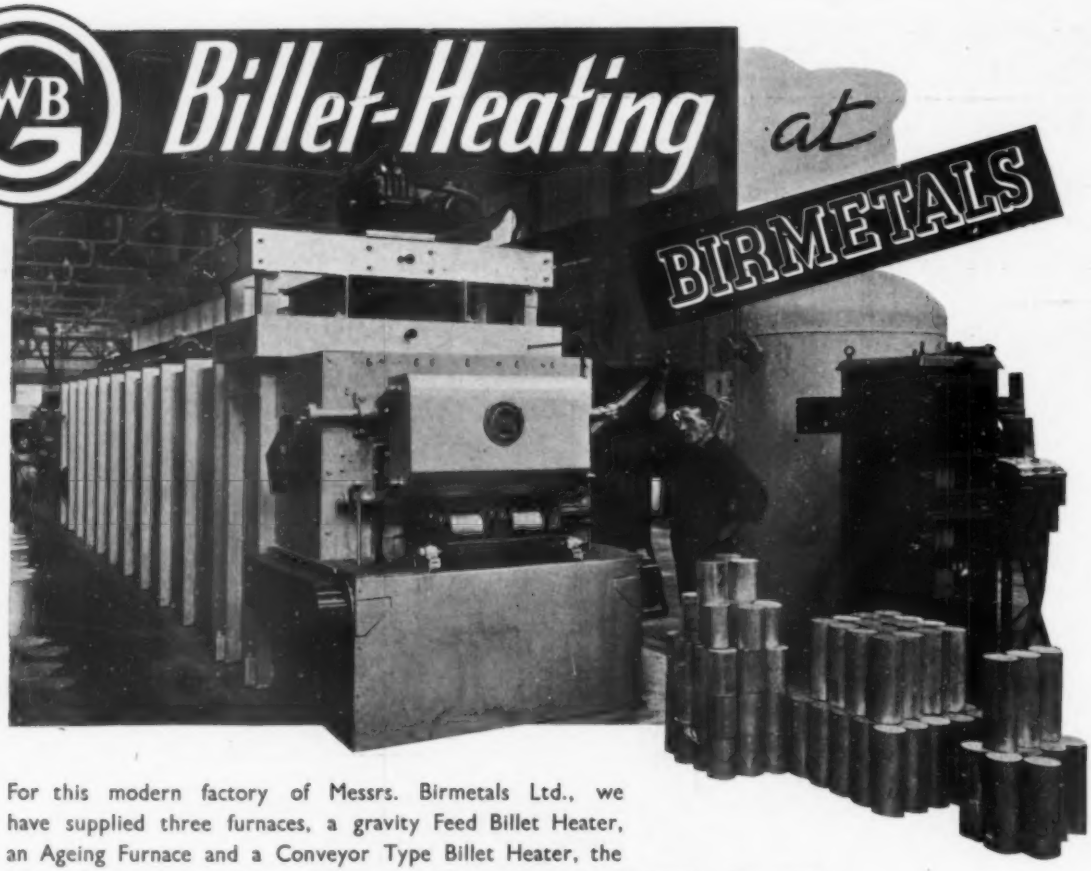

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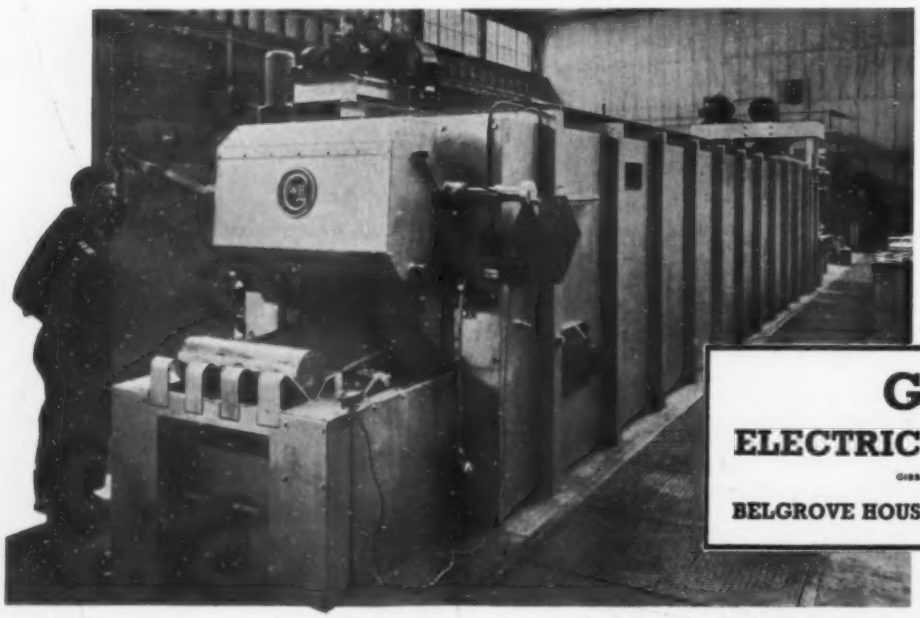

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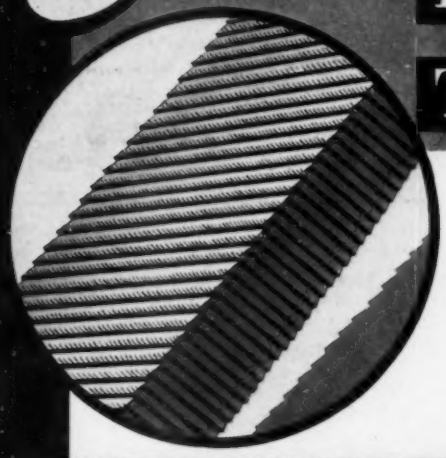

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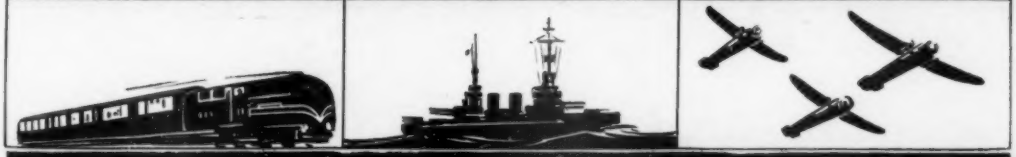

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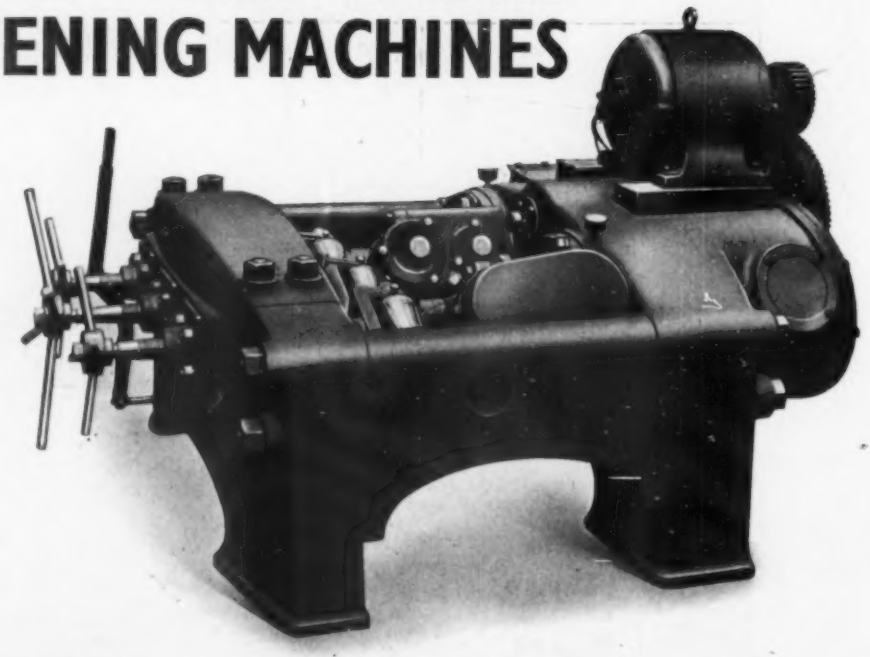

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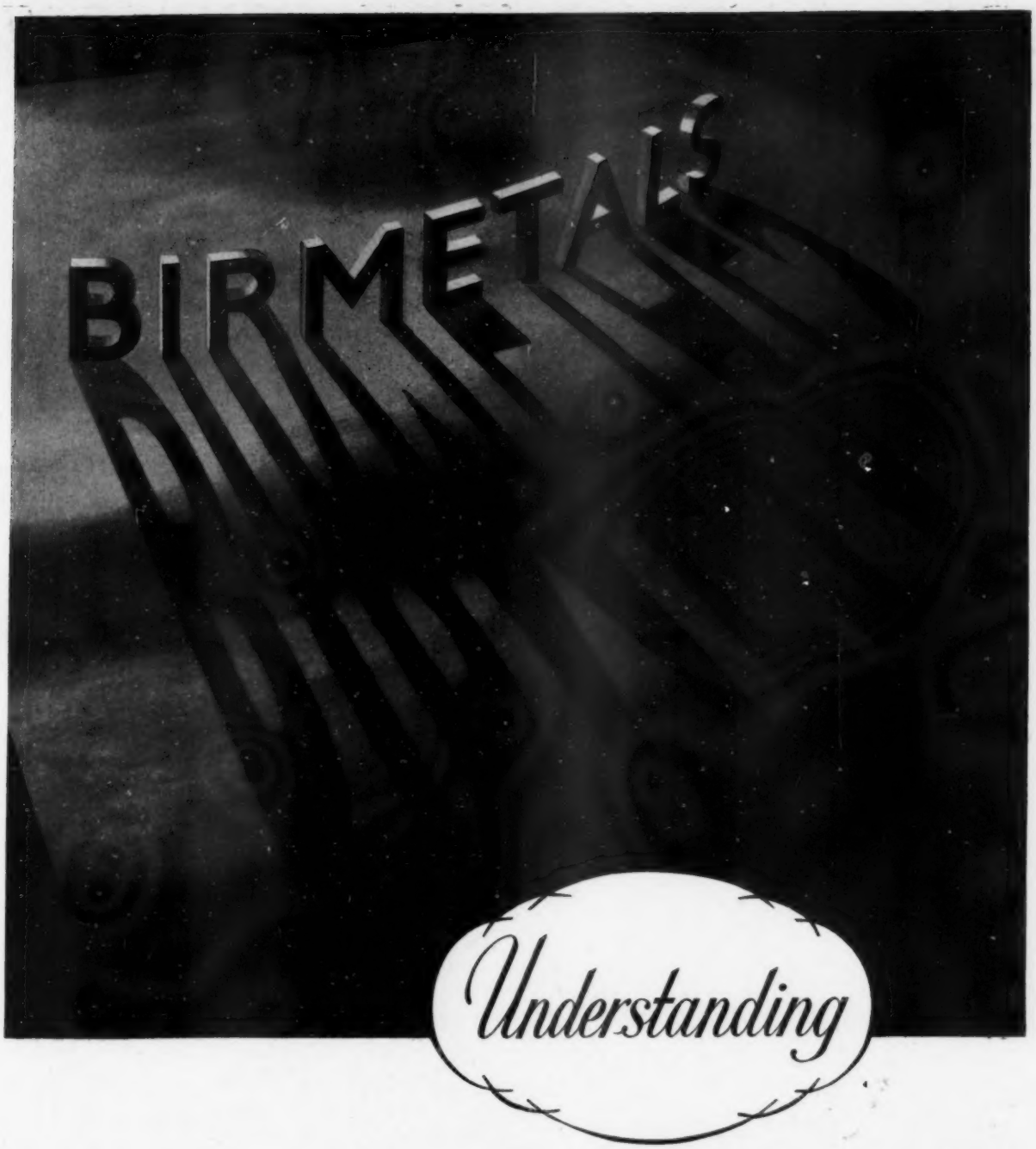

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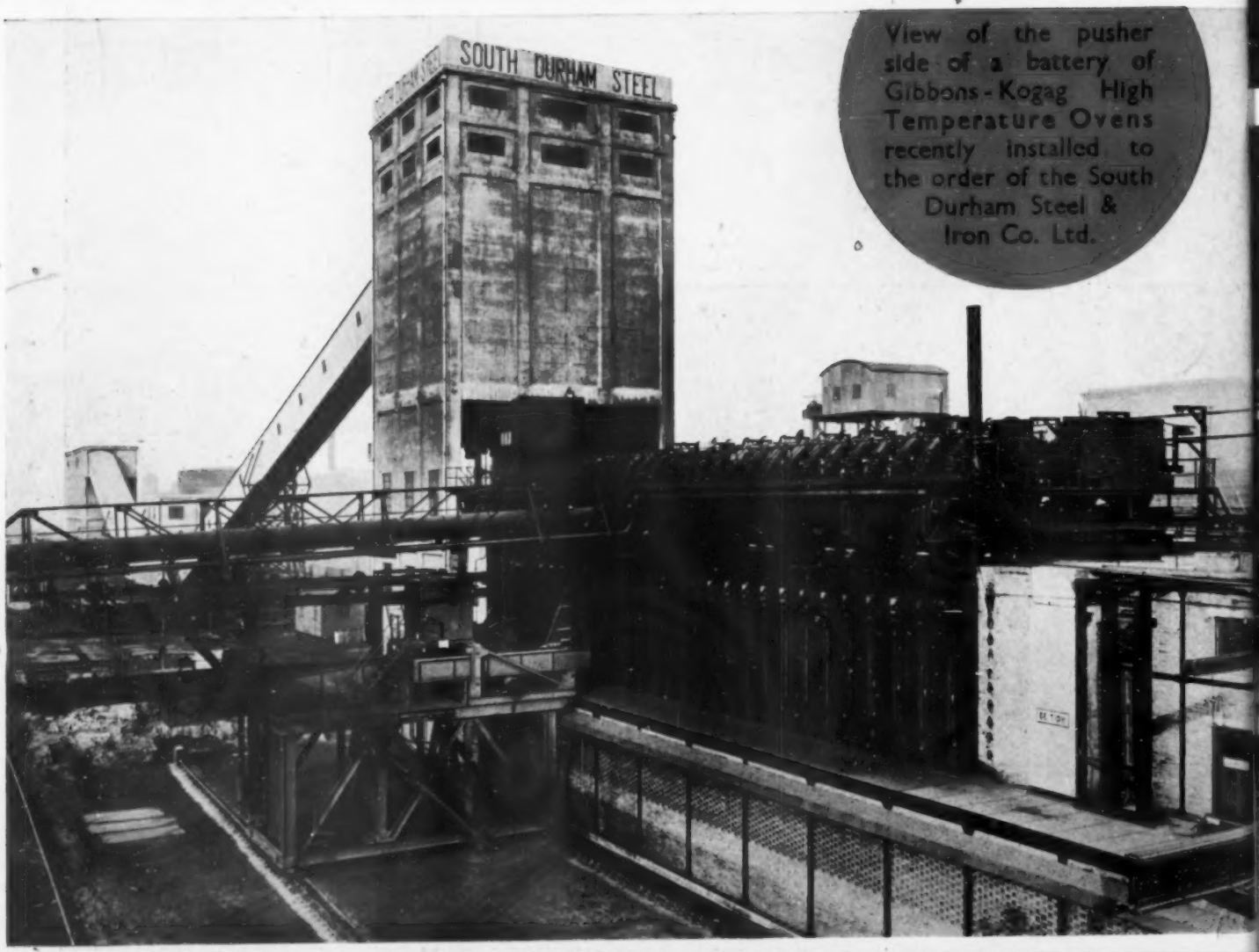

View of the pusher side of a battery of Gibbons-Kogag High Temperature Ovens recently installed to the order of the South Durham Steel & Iron Co. Ltd.

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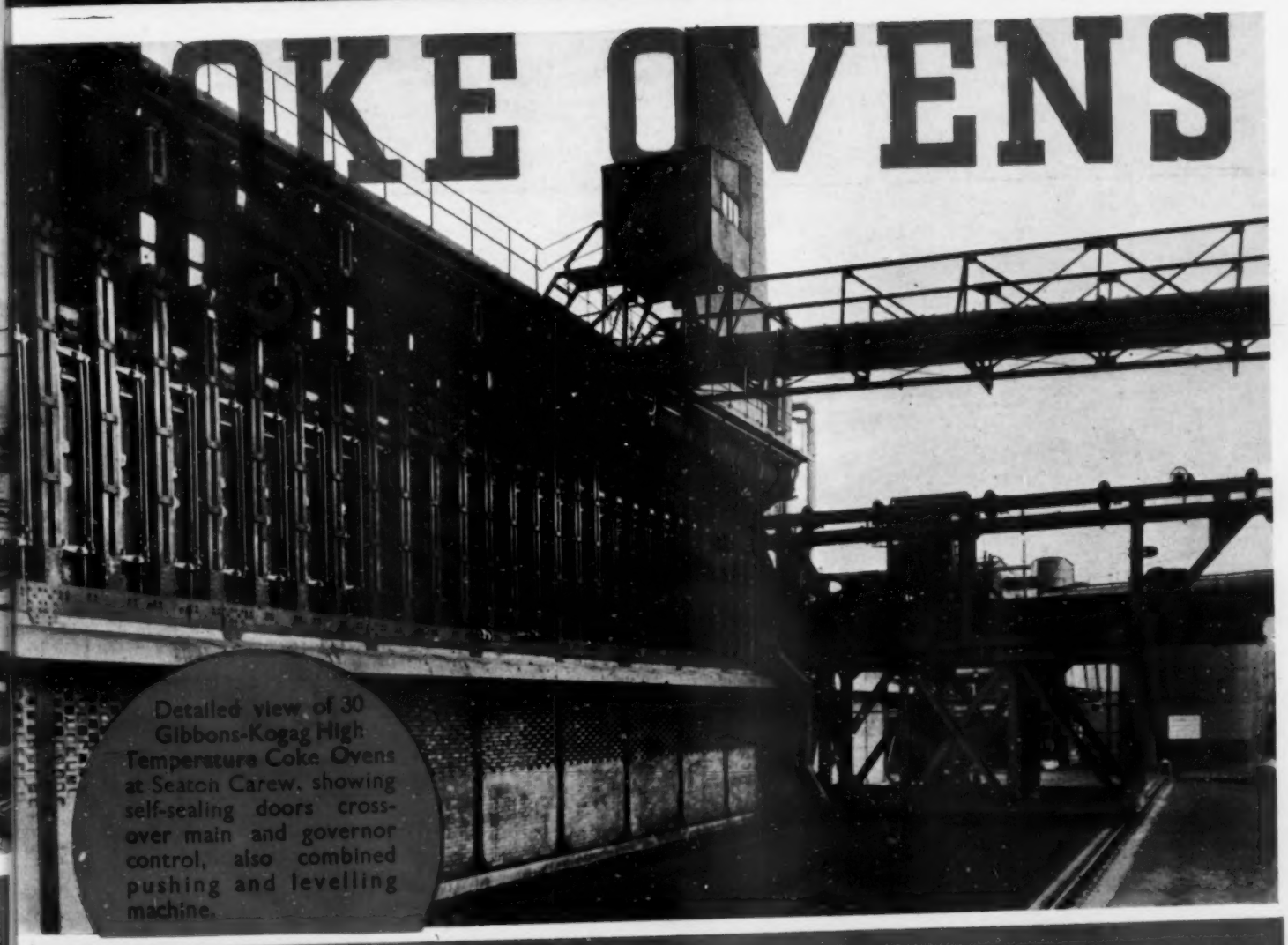

Detailed view of 30 Gibbons-Kogag High Temperature Coke Ovens at Seaton Carew, showing self-sealing doors cross-over main and governor control, also combined pushing and levelling machine.

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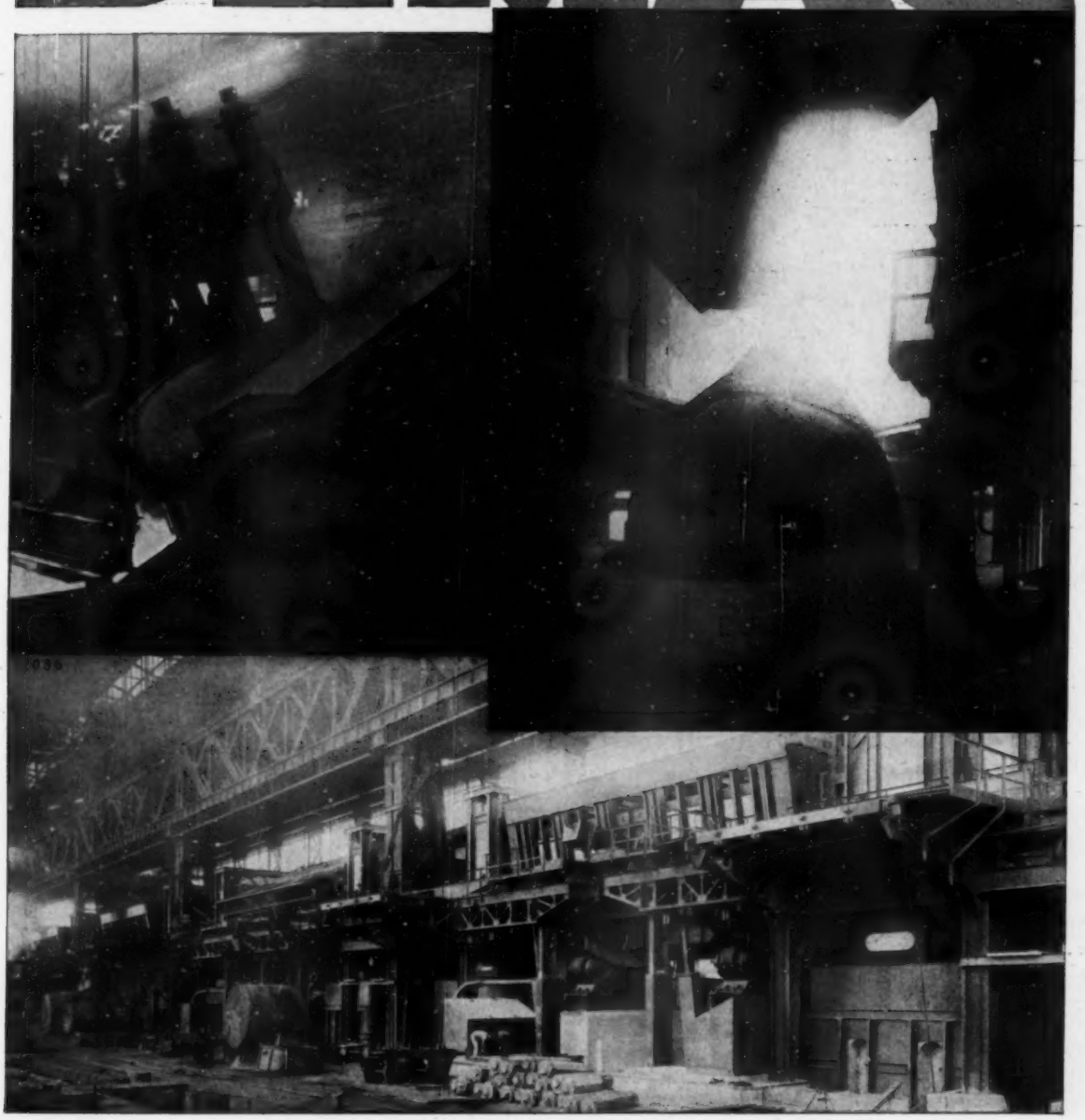

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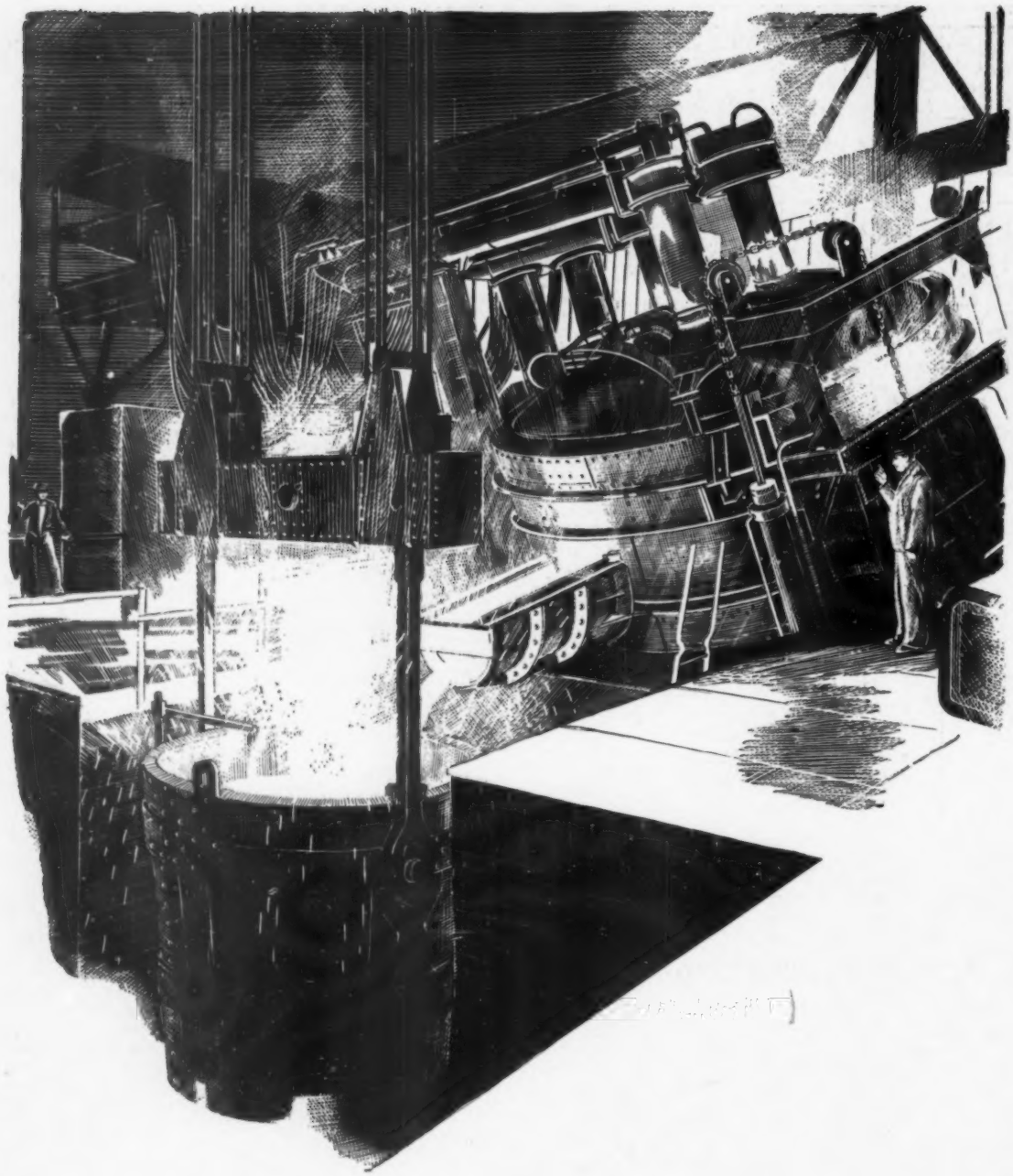

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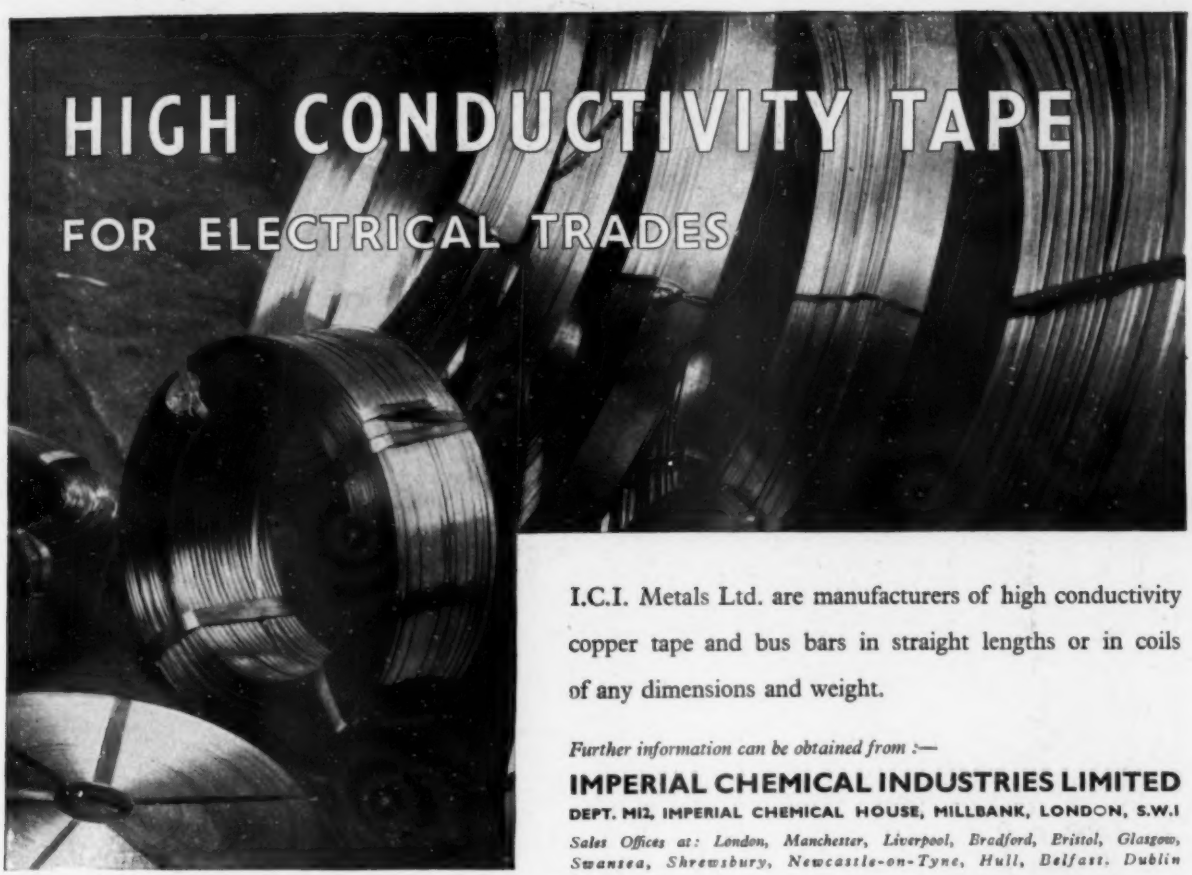

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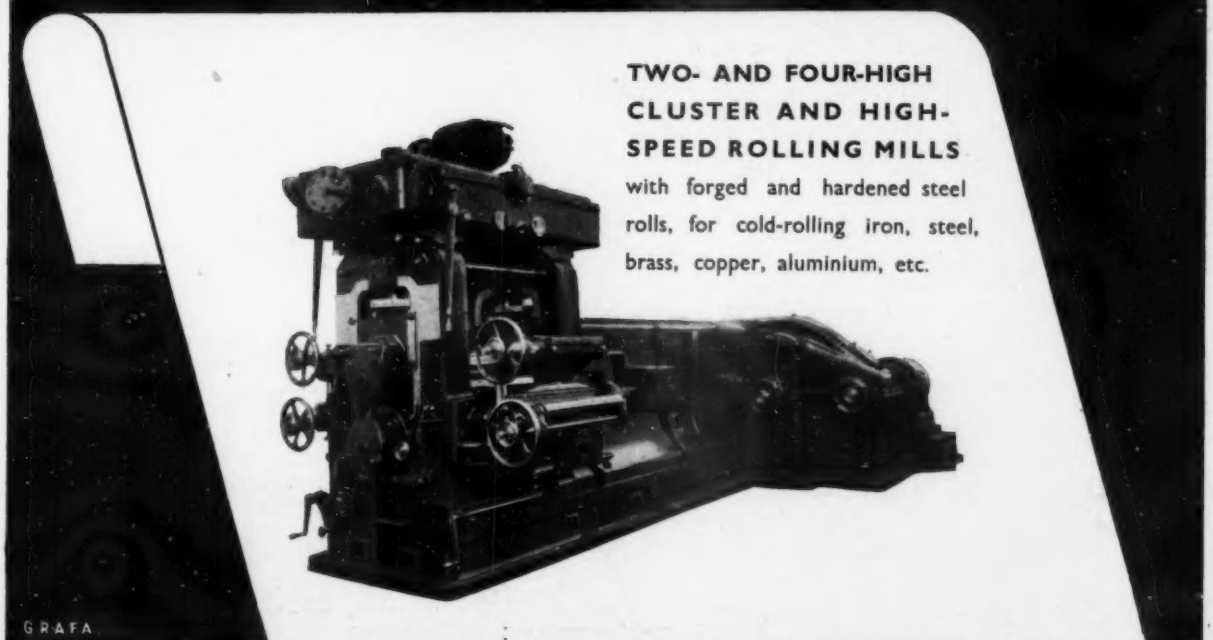

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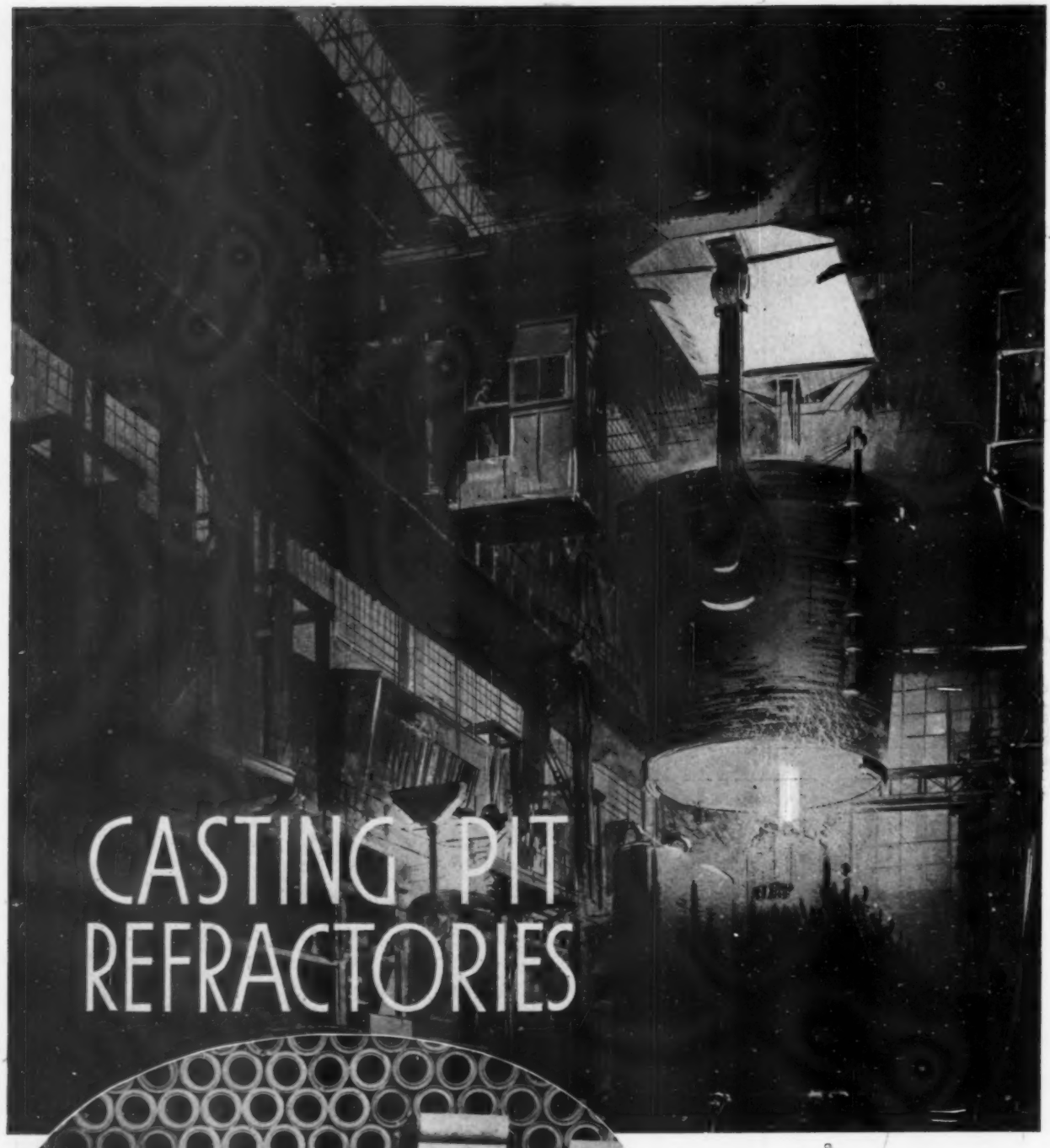

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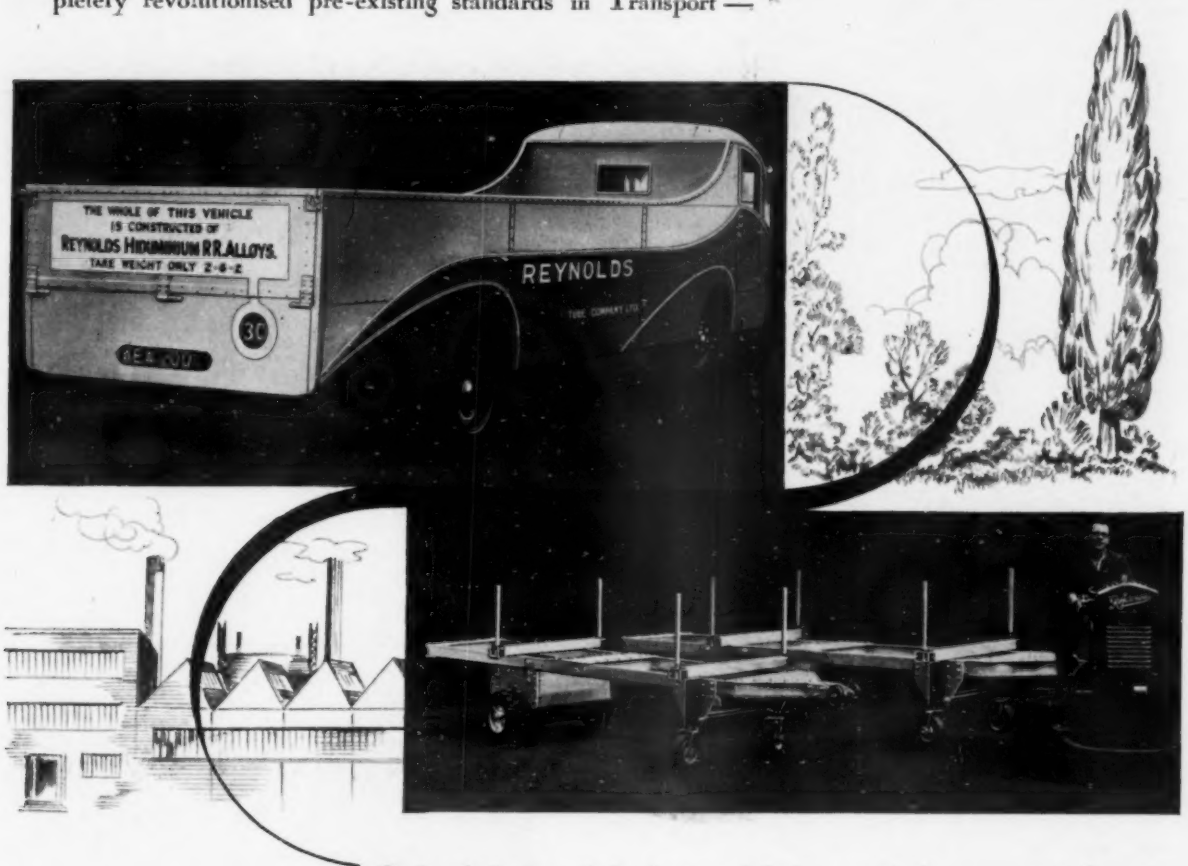

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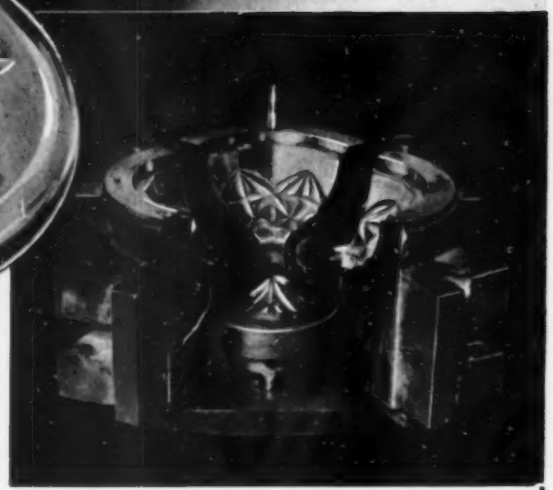

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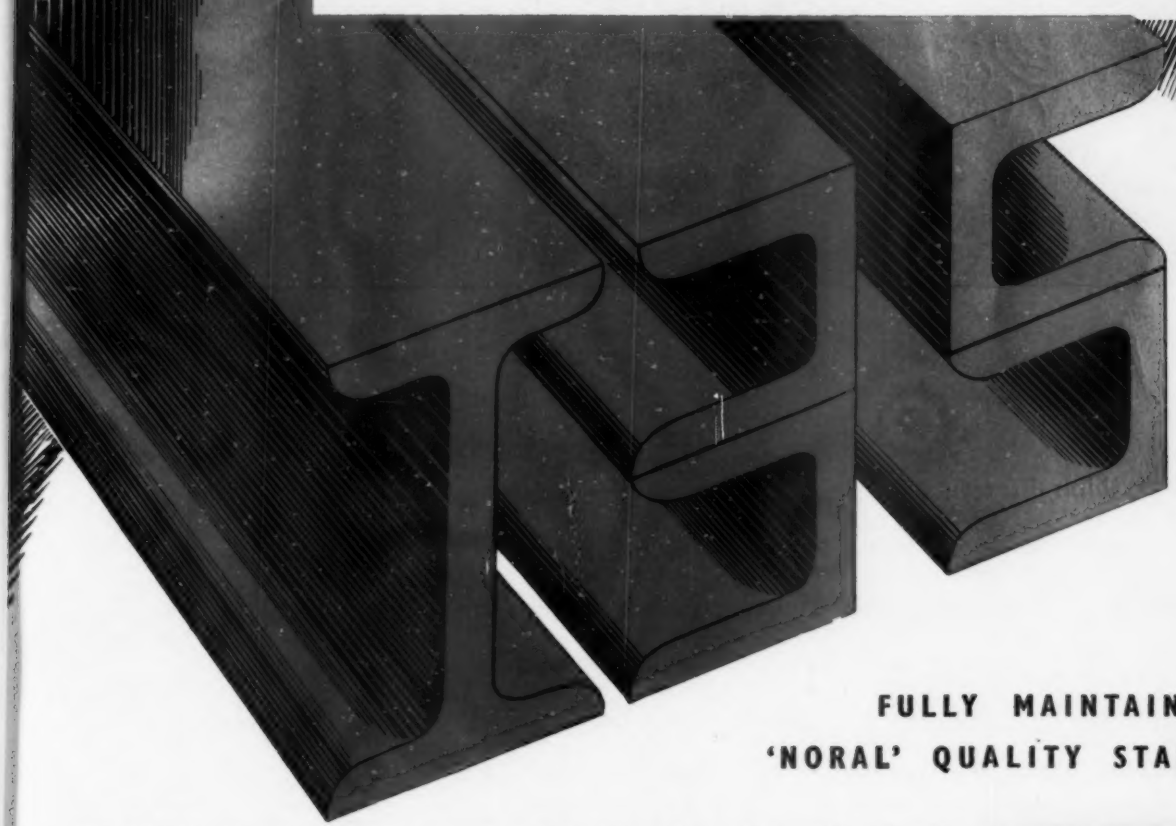

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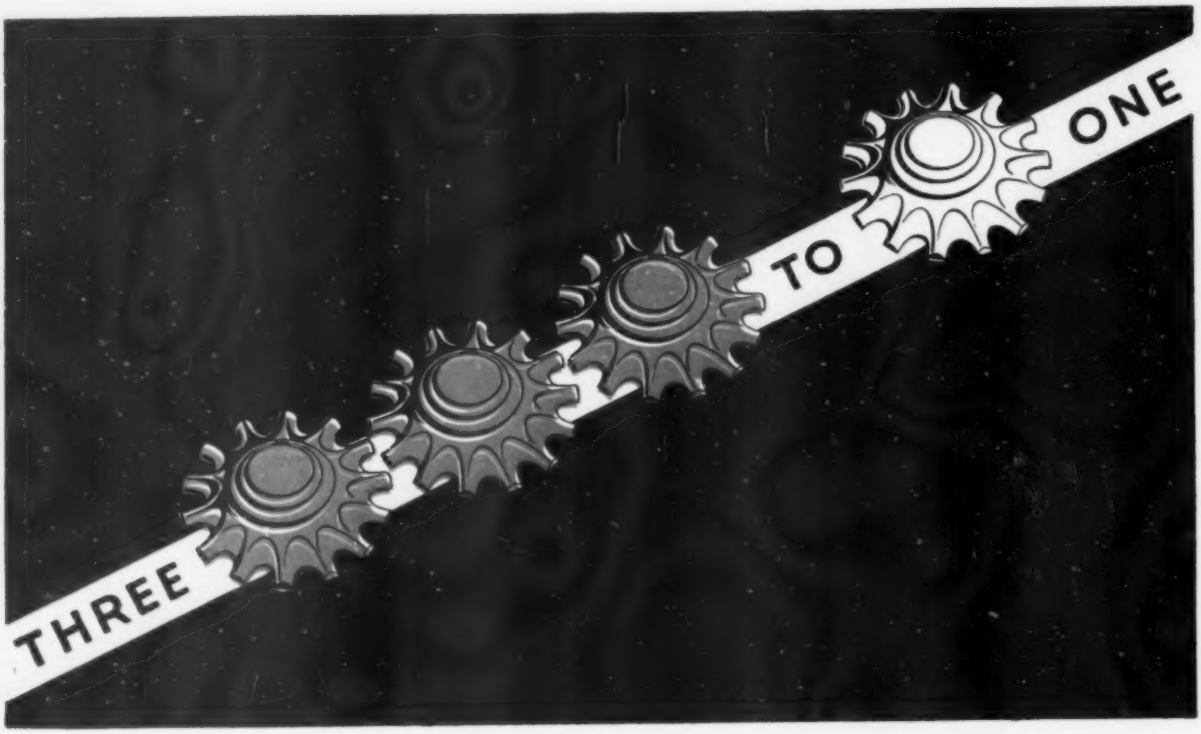

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Experiments with Nickel-Chromium Wear-Resisting Cast-Iron Alloys. By J. E. Hurst 1–4

Some nickel-chromium alloy cast irons have been studied and subjected to service tests for wear resistance, the results of which are discussed. The alloys were subjected to heat-treatment by hardening and tempering, and the results show that they can be given a wide range of properties.

Industrial Management and Production Control. Part VII. Control of Wages. By F. L. Meyenberg 5–7

In this article it is shown that bookings of time spent on each job, and consequent wage payment, can be simplified and improved, and that the possibility of over-systemisation is one which should be avoided.

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The Photographic Emulsion and Its Contribution to Science and Industry 9

Heat-Treatment 11

Controlled Atmospheres in Heat-Treatment Processes. By F. W. Haywood, B.Sc., Ph.D., F.I.C. .. 13–19

An account of the various atmospheres available for heat-treatment processes is given, together with the particular type of furnace best suited to the process. A number of the standard heat-treatments, such as bright annealing, bright brazing and descaling, are cited, together with relevant particulars of specific treatments relating to several materials.

The Heat-Treatment of Cast Iron by Hardening and Tempering. By J. E. Hurst 19–22

Cast-iron machinery components required to possess wear-resisting properties are submitted to a heat-treatment by hardening and tempering. Some investigations on the subject are discussed.

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METALLURGIA

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MAY, 1939. VOL. XX, No. 115.

Experiments with Nickel-Chromium Wear-Resisting Cast-Iron Alloys

By J. E. Hurst

Some nickel-chromium alloy cast irons have been studied and subjected to service tests for wear resistance, the results of which are discussed. The alloys were subjected to heat-treatment by hardening and tempering, and the results show that they can be given a wide range of properties. The experiments and results were discussed by the author at a recent meeting of the Birmingham Metallurgical Society, and this is an abridgment.

THE following notes are confined to the study of nickel-chromium alloys having chemical compositions lying between limits of approximately 2·0—4·0% total carbon, 0·15—1·5% silicon, 3·0—7·0% nickel, and 0·0—2·5% chromium. These alloys may be correctly described as high-duty, hard-wear-resisting cast irons, and the limits of composition cover those alloys which are manufactured and sold under such trade-names as Ni-Hard, Attritard, BF954 and others. In addition to the constituents mentioned, manganese, sulphur and phosphorus are present, all of which have an important influence on the properties and service behaviour of the alloys, and are normally present in amounts within the limits of those usually present in alloy cast irons of this type. Typical compositions of the alloys described as Ni-Hard are given in Table I.

TABLE I.

TYPICAL NI-HARD COMPOSITIONS.

	A.	B.	C.	D.
Total carbon	3·0	2·8	3·6	3·6
Silicon	0·8	0·5	0·8	0·5
Manganese	1·2	1·2	0·8	0·8
Sulphur	0·1	0·1	0·1	0·1
Phosphorus	0·3	0·3	0·3	0·3
Nickel	4·5	4·5	4·5	4·5
Chromium	1·0	0·75	1·5	1·5
Molybdenum	—	0·25	—	0·25

Type A is for light section castings of maximum strength.
Type B is for heavy castings of maximum strength.
Type C is for light castings of maximum hardness.
Type D is for heavy castings of maximum hardness.

These alloys have a hard, white fracture in all but exceptionally heavy-sectioned castings, where the fracture may be mottled to grey according to the mass of the casting. The Brinell hardness of the alloys in the white condition lies between the limits of 500 and 700, and they possess a tensile strength of the order of 22 tons per sq. in. Their essential structure characteristics, in their hardest condition, is that the matrix is martensitic, as distinct from pearlitic in ordinary white cast irons. A typical microstructure is shown in Fig. 1, in which the martensitic matrix is clearly shown accompanied by large masses of the hard cementite carbides.

Alloys of this type find a use in castings which are required to withstand heavy-duty, wear-resisting conditions. Rolls, crushing and pulverising machinery parts used in crushing and grinding operations in the cement, fuel, paper, cereal and rubber-making industries; pump bodies, impellers, pipes, elbows and liners for use in connection with minerals, sand and ash. Sand-blast nozzles, blades and liner plates in sand-handling plants are amongst the

Fig. 1.—Typical microstructure of BF954 alloy in the "as-cast" condition, showing the martensitic matrix accompanied by large masses of hard cementite carbides. ×600.

types of castings used in foundries where materials of this type have given excellent service results.

Service Test for Wear Resistance

An opportunity arose in the plant with which the author is connected to carry out a test under actual service conditions to ascertain the comparative behaviour of alloys of this type. The tests were carried out on liner plates in a rotary ball mill employed in the crushing of chilled white cast iron, for the manufacture of chilled metallic grit for use in shot blasting and cleaning operations. The duty conditions in this mill are exceptionally severe. The material fed into the mill for crushing consists of chilled white iron, having a composition of 2·90—3·0% carbon, 1·25—1·75% silicon, 0·25—0·5% manganese, 0·15% maximum sulphur, and 0·90—1·20% phosphorus.

This material is drastically chilled and treated to give a tough martensitic structure and the Firth diamond-hardness values usually average 850, and lie between the limits of 800 to 1,100 F.D.H. The material normally used for the lining of the mill was manganese steel, and the mill operates at a constant speed and a uniform rate of feed. The average life of four manganese steel linings in this mill was 973 hours, the maximum being 1,093 hours. A number of experiments were made by inserting single plates of the materials to be tested. A single plate, made of BF954 material, inserted in the mill, was taken out after a life of 1,973 hours—an increase of over 100% on the average life and approximately 90% of the maximum life of the manganese steel. The actual chemical composition and mechanical properties of this plate are given below in

Table II. The material was electric-furnace melted, using a spun-refined iron base. These results were sufficiently encouraging to try out a complete mill lining in the same material. The chemical composition and properties of specimens taken from these plate castings are also included in Table II. This complete lining yielded a life of 1,500 hours—an increase of approximately 46% on the maximum, and 53% on the average life of manganese steel under these conditions.

TABLE II.

CHEMICAL COMPOSITION AND TEST RESULTS OF BF954 CASTINGS USED IN BALL MILL CRUSHING CHILLED METALLIC GRIT.

	No. 1. %	No. 2. %
Total carbon ..	2·56	2·68
Silicon	0·49	0·50
Manganese	0·30	0·38
Sulphur	0·064	0·06
Phosphorus	0·090	0·091
Nickel	4·16	4·60
Chromium	1·43	1·58
Firth diamond hardness	477	534
Modulus of rupture	35·4 tons.	40·34 tons per sq. in.
Wear-life	1,973 hrs.	1,500 hrs.

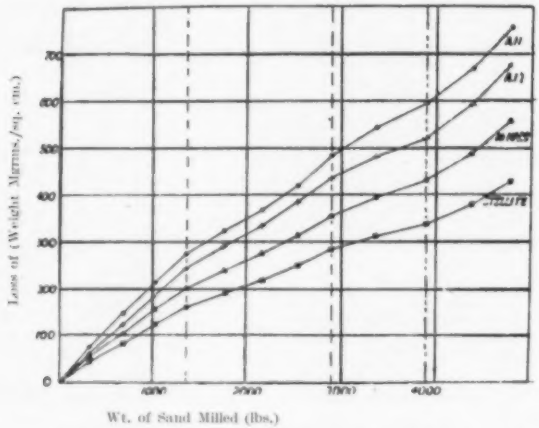

Fig. 2.—Loss in weight of various materials related to the weight of sand milled.

Other similar results, taken from service tests, are available, but these carried out under commercially comparative conditions will suffice to show that in this particular application this nickel-chromium alloy has exceptionally good wear-resisting properties. It is of interest in this connection to refer to the investigations of O. W. Ellis[1], who carried out tests on a number of ferrous materials, including Ni-Hard, cast in the form of balls, in a continuous mill engaged on wet-crushing a silicious material described as "primary bowl sands." The comparative results expressed as total loss in weight of four of the materials tested are shown in the illustration, Fig. 2. In these tests the materials were compared as Stellite, an exceptionally hard-wear-resisting material. The chemical composition of the Ni-Hard and the materials A.11 and A.17 were given as follows:

	Tot. C.	Si.	Mn.	Cr.	Ni.
A.11.....	1·58	1·36	5·85	—	—
A.17.....	1·02	1·32	1·08	3·08	5·95
Ni-Hard	2·72	1·21	0·43	1·58	4·62

The relative losses in weight, as compared with Stellite, reckoning this material as 100, are given in the illustration, Fig. 3. The good results of nickel-chromium compositions of the Ni-Hard type are further illustrated by these investigations.

It is realised that wear conditions in industrial service vary infinitely, and test results of this nature do not permit of any conclusions being drawn as to the wear behaviour of these alloys under conditions different from those tested. In fact, the only final way of evaluating the wear-resistance of a material under any particular combination of conditions is by tests designed to duplicate these conditions. Nevertheless, the accumulation of wear-test results under a variety of conditions does tend to give a general idea of the behaviour of a material, and if to this is added a full and complete knowledge of the physical and mechanical properties of the alloy, the metallurgist is in a better position to predict the probable behaviour of the alloy under other sets of conditions which, for one reason or another, do not allow of actual practical tests. For this reason, it is of importance to acquire as much information as possible regarding the properties of these alloys.

Chemical Composition

In considering nickel-chromium alloys of this type it is convenient to regard them as essentially alloys containing approximately 4·5% nickel and 1·5% chromium. It is possible to draw upon the investigations of Taniguchi[2] to

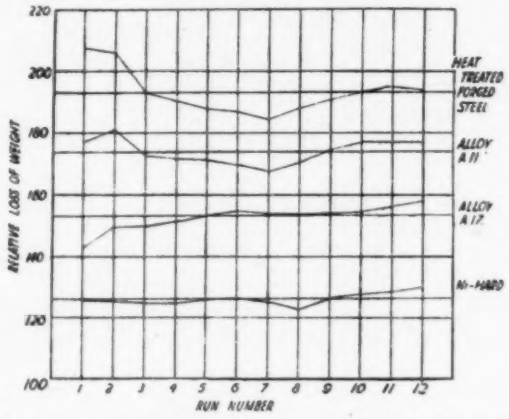

Fig. 3.—Loss in weight of various materials for each run.

illustrate that this combination of nickel and chromium in conjunction with carbon of approximately 3·0%, silicon 0·40%, manganese 0·47%, sulphur 0·033%, and phosphorus 0·5% gives the maximum hardness. Under the conditions of these experiments the increase in nickel and chromium in combination changed the pearlitic character of the matrix to sorbite, and from a nickel content of 3·06%, chromium 1·08%, a martensitic structure appeared until in the hardest specimen, i.e., one containing a nickel content of 3·88%, chromium 1·27%, a decidedly martensitic structure was shown containing some austenite. The further addition of these elements decreased the martensite gradually with the increase of austenite until, in the specimen containing nickel 6·14% and chromium 2·28%, the martensite almost completely vanished and the structure consisted mainly of the austenite matrix and the cementite carbide. The hardness values increase with the change from pearlite to martensite, and decrease again as the martensite changes to austenite. An example illustrating this is given in Table III.

TABLE III.

	Martensitic. %	Austenitic. %
Total carbon..	2·56	2·70
Silicon	0·49	0·39
Manganese....	0·30	0·35
Sulphur	0·064	0·064
Phosphorus ..	0·090	0·090
Nickel	4·16	6·58
Chromium	1·43	1·78
Hardness Brinell 3,000/10..	477 477	340 321
1·2 in. bar F.D.H.	475 450	375 390
Modulus of rupture	*35·40 tons.	45·00 tons per sq. in.
Structure	Magnetic	Weakly magnetic

*Slightly unsound.

1 "Wear Tests on Ferrous Alloys." Proceedings I.B.F. 1936-37, p. 149.

2 "A Study of Alloy Chilled Rolls." *Japan Nickel Review*, vol. 1, No. 1. April, 1933.

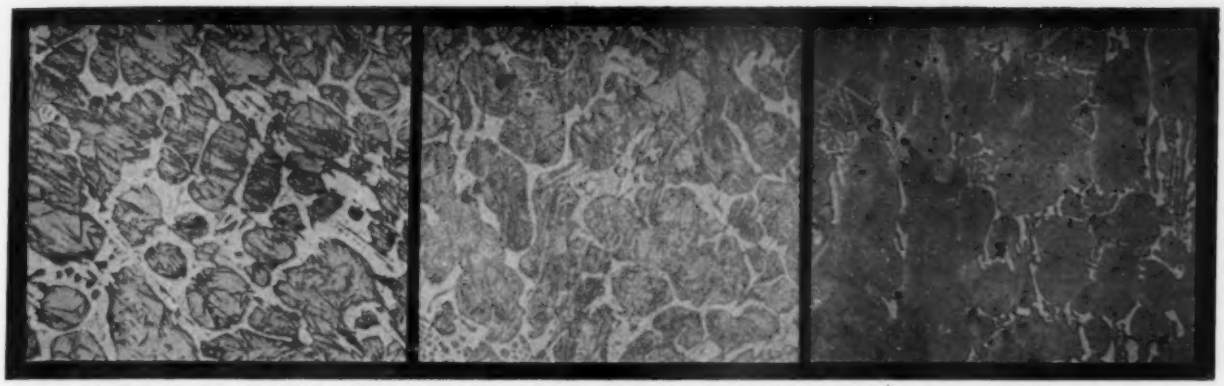

Fig. 4.—Microstructure of martensitic cast iron in the "as-cast" condition. ×130

Fig. 5.—Microstructure of martensitic cast iron quenched in oil from 750° C. ×130

Fig. 6.—Microstructure of martensitic cast iron quenched in oil from 1,050° C. ×130

The test results on these two bars were obtained in the "as-cast" condition, using the standard 1·2-in. diameter bar, and the effect of increased nickel content and chromium in bringing about a lower hardness value is clearly shown. This is the result of the increased amount of austenite present, which is confirmed also by the magnetic properties.

The influence of manganese is important in this same connection, and the test results given in Table IV illustrate this.

In this series of tests the manganese content was increased from 0·38—1·10%. The hardness results on the 1·2-in. diameter bar in the "as-cast" condition show a falling off from 496 to 380, a total of 116 points, and this bar, on test, was found to be only feebly magnetic, indicating an increase in the austenitic condition. The tensile test bars cast to a smaller diameter likewise show a falling off but behave differently, and this will be referred to again later. There are two ways in which this drop in hardness, due to increase in manganese, may be considered. It is possible to consider the total drop of 116 points as being due to the influence of manganese in promoting the austenitic structure. In this case this drop would be due to an increment of 0·72% manganese, or 15·5 points (approximately) for each 0·10% Mn. The alternative is to take into consideration the effect of manganese on the sulphur content. In this case, utilising the results of Norbury,[3] of British Cast Iron Research Association, for the neutralisation of the sulphur, a percentage of manganese of 0·3% plus about twice the sulphur content, in this case 0·18%, making a total of 0·48% manganese, is required to neutralise the sulphur present. The results in the table do not enable us to take this effect exactly into our calculations, but its effect should not be overlooked, and for this reason the drop in hardness, due to the effect of manganese in promoting austenite, may be something less than the former figure.

Reference to the previous table shows that the total reduction in hardness, due to manganese, is about the same as that due to the increase in nickel content from 4·48% to 6·58%—i.e., 2·10% nickel. Under the conditions of these experiments, therefore, manganese has about three times the influence of nickel in bringing about reduction of hardness. Its influence in promoting austenite, whilst more powerful, may be less than this relationship. In any case, too much importance must not be attached to these numerical relations as they only hold under the particular conditions of this experiment. Their value is to show, as would be expected, that the influence is of great importance in this type of nickel-chromium alloy, due to its tendency to promote the formation of austenite and, consequently, bring about a lowering of the hardness value.

The strength values are shown to have fallen substantially with the increase in manganese. The percentage drop in strength is greater in the tensile test-pieces than in the transverse bars, being about 20% in the former and 10% in the latter. In the previous experiment, in which the austenitic condition was brought about by increase in nickel content, a higher breaking strength was obtained in the more-austenitic bar. In this respect the influence of manganese appears to be different from that of nickel.

The other important constituents are of course the carbon and the silicon. Increase in carbon tends to increase the hardness values, and, in general, increase in silicon tends to lower the hardness value, particularly when sufficient is present to have an effect on the amount of free carbide present. Phosphorus is of importance from the point of view of strength considerations, and where maximum strength is required it is advisable to keep the phosphorus down to low limits.

TABLE V.

F.D.H. HEAT-TREATED CONDITION BF954.

Condition.	Exp. 67.			Exp. 72.		Exp. 73.	
As cast	488	464	488	488	488	488	488
Oil quenched, 750° C.	772	824	824	—	—	—	—
,, 850° C.	661	642	662	—	—	—	—
,, 950° C.	488	464	442	—	—	—	—
,, 1,050° C.	328	328	322	312	320	305	320
Oil-quenched, 1,050° C.	Temp. 500			488	518	—	—
,, 1,050° C.	,, 600			671	671	—	—
,, 1,050° C.	,, 700			—	—	7460	719
Water-quenched, 1,050° C.				352	320	305	320

3 *Foundry Trade Journal*, 1929, vol. 41, pp. 79–83.

TABLE IV.

THE INFLUENCE OF MANGANESE ON BF954 MATERIAL ("AS-CAST" CONDITION).

Test No.	Tot. C., %	Si, %	Mn, %	S, %	P, %	Ni, %	Cr, %	F.D.H.		Transverse.		Tensile.
								Trans., 1·2 in.	Tensile, 0·564 in.	Mod.	Def.	Tons per sq.in.
80	2·73	0·49	0·38	0·09	0·09	4·71	1·49	496	465	30·75	0·25	20·4
81	2·67	0·40	0·69	0·09	0·10	4·64	1·54	456	399	20·5	0·21	19·3
82	2·89	0·40	0·90	0·09	0·09	4·56	1·49	436	395	23·25	0·19	14·12
83	2·62	0·38	1·10	0·09	0·09	4·56	1·46	380	393	27·75	0·25	15·4

TABLE VI.

CHEMICAL COMPOSITION OF BF954 MATERIAL IN TABLE V.

Specimen.	Tot. C, %	Si, %	Mn, %	S, %	P, %	Ni, %	Cr, %	Mo, %
Exp. 67	2·56	0·49	0·30	0·064	0·090	4·16	1·43	—
,, 72	2·67	0·52	0·39	0·07	0·10	4·63	1·50	—
,, 73	2·78	0·49	0·36	0·068	0·10	4·52	1·38	0·13

These alloys are susceptible to heat-treatment, and some experiments have been made to ascertain the effect of quench-hardening and tempering. In all cases the tests have been carried out on 1·2-in. diameter bars in the "as-cast" condition. The effect of quench-hardening treatments on the Firth diamond-hardness values is summarised in Table V. The chemical composition of the three specimens dealt with in these experiments are given in Table VI. Quenching at temperatures of 750° C. and 850° C. is accompanied by an increase in hardness. From the higher temperatures of 950° C. and 1,050° C., a drop in hardness down to values of 328, similar to those obtained due to the effect of extra nickel or manganese in promoting the austenitic structure is experienced. Figs. 4, 5 and 6 show microstructure of BF954 alloy in the "as-cast" condition, quenched in oil from 750° C., and quenched in oil from 1,050° C., respectively.

These illustrations show the development of the austenitic structure by quenching from the higher temperature of 1,050° C. More drastic quenching from the same temperature in water has a similar effect, and from the hardness results obtained it would not appear that this more drastic quenching is more effective than quenching in oil.

The effect of tempering, after quenching from 1,050° C., is interesting. It will be observed that tempering at successively higher temperatures is accompanied by the recovery of the hardness value and the restoration of the martensitic condition. By tempering at 700° C., after quenching from 1,050° C. in oil, a diamond hardness value of 750 approximately was obtained, a figure very similar to that obtained by direct quenching from temperatures in this neighbourhood. This is a method by which extremely high hardness values can be obtained in this material.

Low-temperature Heat-treatment.—A study of the effect of low-temperature heat-treatments applied to this material is summarised in Table VII. These results are extremely interesting. The treatment consisted of holding for a period of 10 hours at the chosen temperature, followed by slow cooling. In each case 1·2-in. diameter bars were used, and the chemical composition was the standard BF954, similar to those given in Table VI.

TABLE VII.

THE EFFECT OF LOW TEMPERATURE TREATMENT ON BF954 MATERIAL: 10-HOUR TREATMENTS.

Conditions.	Transverse Breaking Strength.			Brinell Hardness.
	Load, Lb.	Deflect., In.	Mod. of Rupture.	3,000 kilog., 10 mm. ball.
As cast	3,000	0·25	29·40	512
200° C.	4,200	0·44	38·90	477
300° C.	3,600	0·37	34·00	512
500° C.	4,000	0·25	38·20	477
600° C.	4,800	0·40	45·60	512

Even at a low temperature of 200° C. this treatment is accompanied by a substantial increase in strength, and at 600° C. the increase in modulus of rupture obtained is 55% of that of the original "as-cast" condition. This treatment is not accompanied by any falling off in Brinell hardness, and it will be noted is also accompanied by an increase in deflection. (The low figure for 300° C. is probably due to slight unsoundness in the bar.)

No very striking difference is observed, although there is a tendency towards a more clear definition of the structure. It is probably to be expected that low-temperature tempering of martensitic structures of this type would yield improved strength results.

Low-temperature tempering is accompanied by a very substantial increase in strength. This treatment is one of considerable industrial importance. The alloys are, of course, sensitive to the effect of rate of cooling, and the whole of these remarks and experiments are intended to apply to general castings, as distinct from the exceptionally large and heavy masses of castings which are sometimes required for heavy-duty wear-resisting conditions—for example, rolls.

The International Foundry Congress, London, June 12 to 17, 1939

ARRANGEMENTS for the 1939 International Foundry Congress, to be held in London from June 12 to 17, are now complete, and in spite of unsettled international conditions a substantial number of overseas delegates is expected. Official recognition has been granted to the Congress by His Majesty's Government, at whose invitation a reception will be held on Tuesday, June 13.

The official opening of the Congress by the Rt. Hon. the Lord Mayor of London, Sir Frank Bowater Kt.,will take place on the morning of Tuesday, June 13, and after this session Prof. W. L. Bragg, O.B.E., D.Sc., M.A., F.R.S., will present the Fourth Edward Williams' Lecture, entitled "The Atomic Pattern of Metals." Tuesday afternoon, Wednesday morning, and all day Friday, June 16, are to be devoted to the discussion of almost forty papers which will be presented to the Congress. The Friday afternoon has been set aside for a joint meeting with the Iron and Steel Institute.

In addition to these technical sessions, at which all phases of ferrous and non-ferrous foundry practice and metallurgy will be discussed, are the periods—Wednesday afternoon, June 14, and all day Thursday, June 15—which are scheduled for works visits. Eleven companies in London and the Home Counties have kindly consented to open their works to Congress delegates, and the Director of the National Physical Laboratory has generously offered to show a party round the metallurgical section of the Laboratory.

Apart from the reception by the Government, on whose behalf Lord Runciman, Lord President of the Council, and Lady Runciman will receive the guests, other social functions are the annual banquet on Wednesday, June 14, and the reception to be given by Mr. W. B. Lake, J.P., President of the Congress, and Mrs. Lake, on Thursday, June 15. Both these events will be held at the Congress headquarters, the Dorchester Hotel, Park Lane, London, W. 1. Saturday, June 17, will be devoted to an excursion to Windsor Castle and on the River Thames.

A tour of the principal foundry centres of Great Britain has been arranged to follow the Congress, and is divided into two sections—June 18 to 24, and June 25 to 30. Delegates may participate in either the first or both weeks of the tour during which they will be able to inspect twenty-six of Britain's leading foundries. Hospitality will be extended to a large extent by the local branches of the Institute of British Foundrymen.

Both during the Congress and the post-Congress tour, a full programme of sightseeing excursions and visits to industrial establishments has been arranged for ladies.

Further particulars concerning the Congress and the tour are obtainable from the organisers, the Institute of British Foundrymen, St. John Street Chambers, Deansgate, Manchester, 3. Those wishing to participate are asked to make early application on the forms supplied by the Institute.

Industrial Management and Production Control

Part VII.—CONTROL OF WAGES

By F. L. Meyenberg

No form of budgetary control can be fully effective if there is any disparity in the records of work done and the jobs against which labour costs are allocated. In this article it is shown that bookings of time spent on each job, and consequent wage payment, can be simplified and improved, and that the possibility of over-systemisation is one which should be avoided.

WHEN dealing with the problem of wage-booking, I again do not intend to describe one or several of those many "systems" which are perhaps developed with great care for a special case, and often advocated by their originators as the universal remedy for any works in any kind of industry. We are here concerned with the principles only, according to which the problem of wage-booking should be solved; and where examples are given, they have to be taken as such—i.e., illustrating an idea, not as instructions that would be applicable in all cases.

Before going into details, let me emphasise the need for economy of effort. The wage office is dealing with ready cash, and it is obvious that its work must be carried out with utmost care and accuracy. This certainly correct point of view, however, seems to tend only too easily to "over-organisation," in so far as one and the same process or fact is booked in two different ways. That, of course, results in a double checking, but represents unnecessary work, for one method could have been used and with reasonable care would prevent mistakes. It should not be forgotten that the principle of economy governs the problem of wage booking also. It is therefore necessary, before organising the work of wage-booking, to review the situation, and to eliminate all statements and statistics which are not necessary. Admittedly, problems may arise in special cases which need a more than usually detailed study of the vouchers coming from the shops, and these must be filed in a manner easy for reference after use for the main purposes of wage-booking. Care must be taken that such special studies do not lead to a new series of statistics which may not be used afterwards; for this is one of the directions in which "over organisation" starts.

Main Division

The booking of wages can be divided into two parts: the booking of wages in the shops, and the treatment of the various vouchers coming from the shops in the wage office. It is surprising to see that generally, in practice as well as in literature, the second part is dealt with more carefully than the first one. And yet it cannot be denied that the former is the basis of the latter, and that no subsequent accuracy can correct any mistake made in the earlier stage. It should therefore be the duty of any organiser to give the utmost attention to this first booking in the shops. Why that is so often overlooked will always puzzle me; perhaps the reason is that the greater difficulties arise here and that human nature tends to take the line of least resistance. We will not make this mistake, and will attempt to find out which demands have to be fulfilled by this initial booking in the shops.

Some Fundamental Demands

Because a truth should be obvious, it is still worth mentioning; and yet it must be emphasised that it is just these apparently small and self-evident matters which, if neglected, cause great trouble later.

1. No work whatever should be carried out by any workman for which a written order is not at hand or, in emergency cases, made out during or immediately after the work. There are many cases in practice where this demand looks like "red tape," and workmen as well as foremen are only too easily inclined to look at it from this point of view. That does not matter. This condition must be maintained rigidly, or one may lose all necessary survey of what is actually going on in the works, and control will be incomplete. A second question is: who shall make out this written order, and how he shall do it? Various ways are possible, and it will depend entirely on the special organisation of the works as to which shall be used. We are not concerned here with any special "system," but with basic requirements, and will therefore give no answer, but must mention that the very person who is often entrusted with this work is the wrong one—i.e., the foreman. He is the supervisor of the work and of the workmen in the shop, and not a clerk; and any clerical work which he has to do keeps him in his cabin and away from his proper job. This rule should be put aside only in emergency cases.

2. Carefully prepared printed forms should be provided for these orders and for the vouchers of the work done—often the same form can be used for both purposes,—not only in order to diminish the writing work, but especially to guarantee that no important note be forgotten which may be necessary for later identification of the work. What, then, remains on writing into these forms should not be done by the workmen themselves, as is so often the case. The reason for this rule is not distrust to the honesty of the men, but also they are not clerks, but workers; they are not accustomed to this job, and those who are best on the machines and at the bench are often poor writers, and their time is too expensive. It pays very often to have a special clerk doing this work better, and in shorter time.

3. In organising this kind of work, care must be taken first of all of the demands of production control—i.e., it must be easy for the foreman or the departmental manager to obtain from these papers a survey of the work of an individual, or a group of men, during a certain period, or for any special job. These papers must be filed for possible reference later, in case of any complaint, or for statistical purposes. Only after these demands are fulfilled can the wishes of the wages office, of the costing department, etc., be taken into consideration. These departments will best fulfil their functions in this case, when playing the role of a service department to production.

Form of the First Booking of Wages

Many and ingenious "systems" are developed and described in literature, and how these vouchers for wages should be carried out and used in the shops. I have found that almost each type has its advantages and disadvantages, and that the best organisation is that which is sufficiently flexible to be able to use in each shop that form which is most suitable for its particular kind of working. Ardent advocates of the modern trend of booking each fact on a separate slip of paper or card may be astonished to hear that I am, in this sense, defending for some cases the "good old" diary of the individual workman, of course not kept by him, but by the above-mentioned clerk. It gives, for example, in repair shops a survey of the work of a fitter sometimes working on this, sometimes on that plant,

as no slip-system can offer without special work. That may be of such advantage to the supervising engineer that the disadvantages of the diary-system could be disregarded.

Fig. 12 gives an example of a wage ticket which has been used in this form in a factory for various products for hourly fixed rate as well as piecework wages. It may illustrate the various circumstances which must be considered in order to give all necessary details. On the other hand, I can imagine that this form could be used directly at a finishing bank of a rolling mill or in a machine shop of a big metallurgical works. There an individual work-piece has to undergo various operations one after another, and for each of these operations a special wage ticket is necessary, differing from the previous only in certain details. These wage tickets can be clipped together in the form of a booklet and accompany the material from one operation to the other, that ticket being torn out of the booklet which represents the operation just carried out. In this case the wage tickets identify to a certain extent the material already distinguished by stamping or painting, as explained in one of our previous articles.

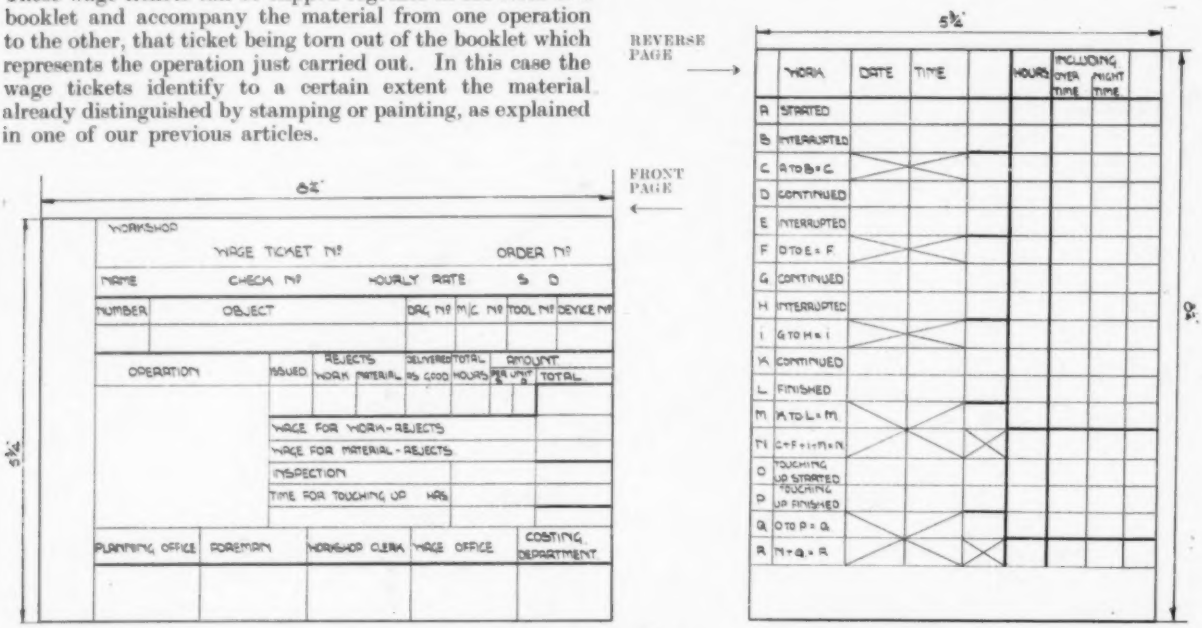

Fig. 12—Wage Ticket

It may be emphasised that in each case for work at a fixed hourly rate as well as for piecework, the time actually taken should be entered on the wage ticket. That is necessary for costing purposes in case of work at hourly rate, and also for checking the piecework prices on piecework. The reverse of the wage ticket, as shown in Fig. 12, is used for this purpose, the carrying out of which is not so easy as may appear at first glance. There is certainly a tendency for men to obstruct this measure, and even the management sometimes declares it to be superfluous. The objection of the men may result from the mistrust that this checking of piecework prices is done with the intention of price-cutting. That can and must be overcome by a frank and honest wage policy, and the very discussion of this question of entering the actual working time into the wage tickets may provide an opportunity to the manager of the shop to make a clear explanation of his standpoint and afterwards to show that he stands by his word. The objection of the management mostly results from the consideration that the piecework prices, if once fixed, should not be changed, and that it therefore does not matter how long a time the men use for a special job. That means a misunderstanding of facts; a change in the piecework price is necessary if a mistake has been made in fixing it, and if the working conditions have changed considerably. Both can be found out only by continuous checking as the "rate-fixer" will not always be informed by the people responsible for production when a change or improvement of production methods has taken place. Thus "good" and "bad" piecework prices will occur, even if the original ones have been correct, and the bad consequences connected with them will result. Now this entering of the correct working time is by no means an easy job. As already mentioned, there is no other way to come to it than by limiting the work which the men have in hand to a single job, indicated by the one wage ticket which is given him. He has to return it when the job is finished, or must be interrupted, and should begin a new job only after receiving the wage ticket belonging to it. Suitable arrangement of the layout of the shop as well as of the organisation is necessary, to avoid too far and too frequent walks of the men to the place—generally the foreman's cabin—where the tickets are issued. I know that it is often said that what has been described above is an exaggeration, and this "system" could never work in practice satisfactorily. Experience has shown me on various occasions that that is wrong, and that a clear survey of the work actually done in the shop is more than worth the organising and clerical work entailed. Of course, the difficulties of introduction are not small, but experience has shown that when it is running it is simple in operation, and the very workmen who may have opposed so strongly at the beginning are then the most eager advocates.

Wages Summaries Per Worker and Week

The total working time of the men, formerly controlled by the watchman at the entrance of the works, is at present mostly checked by the "stamp clocks," the construction and use of which can be taken as generally known. Often an attempt is made to combine the workman's diary or the wage tickets in some way with the stamp cards used in these clocks, and the idea is attractive at first glance. Practice has shown that this can be recommended only in rare cases; I have seen more works, where the printing on the back of these cards for this purpose has not been used than those where it has actually taken place in the intended manner. Of course, in the case of piecework a comparison of the total working time as given by the stamp cards of a man, and as given by the number of wage tickets finished by him in the same period, must be made, but that should be done on a separate form, with sufficient space to show in detail how the gross earnings during the week are made up by the wages for the various jobs, which additions for overtime, etc., have been added and which deductions for insurance, etc., have been made, thus obtaining a net sum, which will be paid in cash. When these summaries are made by the wages office so that they can be distributed to the men, say, on Thursday for the

preceding full week, the men have time to check them and make any claims for adjustment before the money is actually paid on Friday. Thus one can avoid differences not being cleared in time and money paid the next week which should have been paid in the previous week. May I take the opportunity to point out that the ratio of such claims or adjustments to the total number of workmen is a very good criterion of the organisation of the wages office. I remember quite well a factory occupying 1,200 to 1,300 men in a very complicated production of a different kind, where the average number of such adjustments per week, taken over a whole year, certainly did not exceed two or three.

The Work of the Wage Office

It is the duty of the wage office to collect all wage tickets, stamp-clock cards, and other vouchers used in the shops for recording working times and wages, and to draw the necessary conclusions from the figures and dates they contain. As they handle cash, forming the connection between the workmen and the accounts department, the confidence of the men is based to a great extent on the correct and fair payment of their earnings ; and it is only natural that this work of the wage office is generally carried out with utmost care and accuracy. And yet it is often found that the proper organisation of this office is built up in a rather haphazard manner. That can best be avoided or improved by a clear analysis of the functions of this office.

The Purposes of the Wage Office

They are manifold : First of all, it is its duty to find out for each workman whose name is on the wage list the true earnings during the last finished wage period (mostly a week) ; it has to put together these individual earnings in the pay roll, so that the necessary ready money can be asked for, paid into the individual wage boxes or packets, distributed to the various shops and handed over to the men at the right time (usually Friday of the following week).

Secondly, it has to provide the works manager, his departmental managers and foremen, with all statistical data necessary for judging the correctness of the rates, hourly-fixed as well as piecework, in relation to the work done ; and the earnings of the individual worker as well as certain groups of workers per hour, per week, and per year ; average figures of these items for comparison purposes ; further numbers of the workers divided according to age, sex, trade, actually working, and absent because of illness or leave ; labour turnover, with necessary details ; finally, the number of working hours, divided into normal hours and overtime, net working time, meal times and stoppages, etc. From these data all conclusions must be drawn and issued in handy form, in so far as the works management asks for it, but no more, for statistics which are not used represent unproductive work. Careful consideration is therefore necessary to make the right selection.

Thirdly, the wage office has to provide the costing department with similar information as it does to the works' management, the details of which are determined by the system of accountancy adopted in the works, and therefore variable from works to works. (To enter into a comprehensive discussion of this matter would be outside the scope of this article. Of course, it is not only possible, but even probable and desirable, that figures prepared for one of these three groups of purposes can be used for one or both of the others.

Collecting and Separating Wage Figures

If we consider the work of the wage office from these aspects we find that it consists of—

1. Collection of wage figures } from different points of
2. Separation of wage figures } view.

1. The collecting of wage figures takes place first of all in the pay-roll, which, as the name indicates, is the basis of actual payment of the men in ready cash. Therefore it contains against the name of each worker all details, how his gross earnings are transformed into net earnings and the payable sum by means of the various deductions or stoppages for insurances, money advanced, etc., and the sub-division of money in paper and coin, for distribution into the individual pay-packets.

The pay-roll should also give, however, such other details as profession, working hours, either against piecework rate or fixed hourly rate, overtime, etc. ; for these are necessary for many statistics which are best based on the pay-roll.

2. The separating of wage figures is less commonly used. It is based on individual accounts for each worker, again containing about the same figures as the pay-roll, but so arranged that a survey of the weekly, quarterly, and yearly earnings of the worker are obtainable without special investigation of the pay-roll. These accounts are sometimes connected with a muster-roll of the workers, giving all necessary personal details about each man—his age, address, date of engagement in his present occupation, wage rate, promotions, etc. These accounts have proved useful in many cases, especially in big factories, as a basis for negotiations with the men themselves, the works' council or trade unions, in answering questions of the Inspector of Income Taxes, etc., also for some statistics which may be required. Still, it cannot be denied that these accounts mostly, made out in the form of card indices, cause considerable work, and it is certainly necessary to investigate in each case—i.e., for a special works—whether the possible advantages counterbalance this increased work which has to be done in the wage office.

Conclusion

One point of view which is often overlooked when carrying out such investigations, has a more universal and greater importance than is generally recognised :—

> Everything possible should be done to make the flow of work through the wage office as even as attainable.

The nature of the work of this office has the opposite tendency and readily affected by slack and rush periods. If, then, a special investigation coincides with a rush period, the staff is insufficient, and either a generally uneconomical increase of the staff takes place or complaints about the inefficiency of the wage office arise. Therefore all measures which facilitate such special investigation should be welcomed, as, for example, the accounts of the individual workmen.

Soldering Lead Pipes

THE International Tin Research and Development Council and the Lead Industries Development Council have prepared a booklet which gives valuable advice on soldering lead pipes and sheet metals. It is shown that solders, containing tin and lead, alloy with the metals they are used to join together. Clear explanations and illustrations are included, the purpose of fluxes, and need for " tinning " are dealt with, and a detailed description of wiped joints is one of the most useful in the booklet.

The various officially recognised grades of solder on the market are defined, and their suitability for various purposes is commented upon. One of the very informative sections is that which deals with the significance, if any, of surface appearance. The sixteen photographs and diagrams show methods of working and interesting applications, some showing how soldering process can be adapted to fit in with quantity production methods.

Copies of this 24-page booklet can be obtained free of charge on application to the International Tin Research and Development Council, Fraser Road, Greenford, Middlesex.

Second Report of the Alloy Steels Research Committee

ORIGINALLY formed in 1934 as a Joint Committee of the Iron and Steel Institute and the British Iron and Steel Federation, a comprehensive programme of research was drawn up, the preliminary results of some of which were published in 1936 in the Committee's first report on alloy steels, and now, about five years after the Committee's inception, further valuable researches are published which indicate satisfactory progress with the programme laid down.

The Delta Region of the Iron-Nickel System

The report is divided into sections, each of which is presented by the investigator or group of investigators responsible for the work. The first section following the introduction contains an account of the study of the delta region of the iron-nickel system. A portion of the constitutional diagram up to 15% of nickel and in the temperature range of 1,550°–1,350° C. is defined. This region includes the delta-phase field, which at the peritectic temperature extends to 3·4% nickel. A duplex field extends to 4·5% nickel, and a peritectic horizontal at 1,512° C. intersects the liquidus curve at 6·2% nickel The diagram is based on the results of thermal analysis carried out in a valve-energised high-frequency induction furnace, on alloys prepared from metals of high purity. An incidental determination on iron of high purity gives the melting point as 1,533 ± 5° C. and the S–y transformation at 1,388 ± 5° C. A table gives the results of the present work in comparison with data obtained previously by other investigators.

The Sealing of Steels in Sulphur-free and Sulphur-containing Furnace Atmosphere

Another section contains further valuable data concerning the sealing of steels in sulphur-free and sulphur-containing atmospheres, which will be of considerable assistance to those concerned with problems of sealing during heat-treatment. The work also throws light on the mechanism of sealing, particularly with regard to the effect of sulphur dioxide.

The data includes tests at 650° and at 1,000° C. on a range of carbon steels and also on 5% nickel, 4% silicon, silicon-chromium, 1 and 8% aluminium steels, 1½ to 13% manganese, 12 and 18% chromium, and 18/8 chromium-nickel steels. In addition to tests in a " neutral " atmosphere, the effect of carbon monoxide, sulphur dioxide, and oxygen additions has been studied. It is shown that the presence of sulphur dioxide, even in small quantity, or of oxygen increased the rate of sealing. This section contains interesting results concerning the effect of alloys in the steel.

An Electron-Diffraction Study of Oxide Films on Iron

The advantages and limitations of electron diffraction are compared with those of X-rays, and a number of recent applications are briefly described in a section. Results obtained by the election diffraction examination of oxide films formed on Armco iron under controlled conditions in a high-vacuum furnace at temperatures up to 1,200° C. are tabulated, and it is shown that under certain conditions the initial surface finish may determine the nature of the oxide film.

The subject as presented is of fundamental interest and mainly exploratory in character, and appears to open up a valuable field, particularly in regard to the scale-resisting steels. An interesting feature of the present work is the discovery of a hexagonal form in a low oxide of iron which is structurally related to the underlying metal, and it is thought that this may provide the basis for an explanation of the resistance of certain steels to descaling and of the great adhesive qualities of such films.

Titanium and its Effect upon Iron and Steel

A review of the literature on titanium and its effect upon iron and steel is given in this section; it includes an exhaustive summary of published data in this field. The first part deals with the preparation of pure titanium and the manufacture of titanium alloys, and an account is given of investigations on the constitution of the iron-titanium and iron-carbon-titanium systems. The second part describes the known effects of titanium upon the physical and chemical properties of iron and steel. Reference is made to precipitation hardening in iron-titanium alloys, to the effect of titanium on the quench-ageing of mild steel, on its resistance to oxidation and corrosion, and to the deoxidising action of the element.

Changes in the Torsional Elastic Limit of some Alloy Steels

Further work is described in another section which was carried out to check the changes in torsional elastic limit with temperature found to exist by Goffey and Thompson in 1923, following the discovery by Sykes that there were no changes in the specific-heat curves at the temperatures corresponding to the anomalous torsional elastic limits. In the case of 0·40% carbon steel minima were found at 50°, 120°, and 270° C., and maxima at 90°, 170°, and 300° C. Similar results were found in 3% nickel steel, and a sharp minimum in 18/8 chromium-nickel austenitic steel at 340° C. is attributed to the presence of nickel atoms in the alloy.

The results appear to establish beyond question the presence of such change-points in the torsional-elastic-limit curves, but criticism may be levelled at certain aspects of the experimental procedure involved, and the Committee have in mind further work with a view to confirming the indications of the present research.

Influence of High-frequency Electric Currents on the Properties of Steel

Since the work of Herbert in 1929 the influence of magnetic fields and periodic oscillations upon the properties of both ferrous and non-ferrous metals has been the subject of a variety of claims, and the work described in this section represents an attempt to determine the effect, if any, of high-frequency electric currents upon the properties of steel. The depth of hardness of carburised mild steel, the ageing of carbon, nickel-chromium, and 18% tungsten high-speed steels, the tensile strength of carbon steel strip, and the impact value and grain size of carbon steel all formed the subject of critical experiments. In no case was it possible to attribute a definite effect to the high-frequency current.

The A_3 Point in Iron-Cobalt and Other Alloys

A further study of the A_3 point in iron-cobalt and other alloys, following upon the study of the iron-cobalt system published in the Committee's first report is continued in a section. Previous work suggested that cobalt is an element which tends to extend the γ field, and in order further to study the A_3 point accurate X-ray measurements have been made of the lattice parameters of alloys containing up to 70% of cobalt. The results of these measurements indicate that additions of cobalt up to 18% tend initially to increase the lattice spacings, and that further additions cause a reduction, although the fall is arrested at 45% and there is a slight subsidiary maximum corresponding to 48% of cobalt. Slight evidence of an ordered arrangement

in alloys containing 45–50% of cobalt was detected. The principles outlined in the effect of increase in lattice dimensions on the α—γ change are applied to other systems, especially in the iron-chromium system, and are shown to account for the closed γ-loops in these systems.

Thermal Treatment

Work of Sub-Committee A on thermal treatment was introduced in the Committee's first report, and in the present report further work is discussed. It contains the results of determinations of heating and cooling curves on twenty-one steels. Varying rates of heating and cooling were used, and certain steels were investigated in greater detail, including comparisons between rimming steel and solid steel of very low carbon content, and a detailed comparison between a nickel-chromium steel and a similar one to which molybdenum was added. The 13% manganese steel and the high-speed steel also received more detailed study. The selected alloy steels were examined microscopically as well as by thermal methods.

The Hair-line Crack Sub-Committee

In view of the conflicting explanations that have been offered regarding the origin of small cracks known as "hair-line cracks" or "snowflakes," the Committee have appointed a Sub-Committee to investigate the matter, and in the present report a preliminary statement is made by this Sub-Committee, which is now engaged in a detailed study of the phenomenon.

Scientific Basis of Corrosion-Fatigue

A preliminary account of certain investigations into the scientific basis of corrosion-fatigue is given in a section. It is devoted mainly to a description of the apparatus and experimental method, and no attempt is made, for the moment, to interpret the results.

The Intermediate Transformation in Alloy Steels

The report includes a description of some recent work on the intermediate transformation in alloy steels. Many alloy steels differ from carbon steels in that, when cooled continuously at such a rate that the pearlite point is suppressed, they do not always give martensite or mixed martensite and austenite as carbon steels do, but may transform in the intermediate temperature range between 550° and 250° C. The product of this intermediate transformation differs in mode of transformation and in microstructure from those of the pearlite point on the one hand and the martensite point on the other. The properties of the intermediate product in the untempered and tempered conditions differ from those of pearlite and from those of tempered martensite. Since these transformations in the intermediate range are not unusual in commercial operations, a wider knowledge of the subject is of value.

The Determination of the Transformation Characteristics of Alloy Steels

The final section of the report is devoted to a description of a dilatometric study of the isothermal transformation of unstable austenite in alloy steels, and it is shown how three transformation characteristics—namely, the period of induction, the transformation velocity, and the completeness of transformation—can be deduced from the data obtained. A method is described for determining transformation velocities, which may be applied over a wide range of temperatures. The application of the method is shown by examining the effects of additions of nickel and chromium, separately and together, upon the transformation of steel containing 0·30% carbon.

The Council of the Iron and Steel Institute announce that :—

Mr. John E. James, Chairman of the Lancashire Steel Corporation, Ltd., has been nominated an Honorary Vice-President.

Mr. J. Sinclair Kerr, Director of the Lancashire Steel Corporation, Ltd., has been elected a Member of Council.

The Photographic Emulsion and Its Contribution to Science and Industry

THE annual May lecture of the Institute of Metals was delivered by Dr. Olaf Bloch recently, in the Hall of the Institution of Mechanical Engineers. Dr. C. H. Desch, F.R.S., President of the Institute of Metals, was in the chair. The subject of the lecture was the photographic emulsion, which, Dr. Bloch said, consists of a finely divided suspension of one or more of the halides of silver in gelatin, and in its preparation every detail, from the mixing of the chemicals to the coating of the finished emulsion upon its support and the final drying process, is important and vitally affects the quality and the characteristics of the product.

Two stages in manufacture are recognised, the first taking place just after the formation of the silver halides, when the larger grains are allowed to grow at the expense of the smaller (Ostwald ripening) and the second stage, when, after washing out the soluble salts, the emulsion is digested to bring about an increase in sensitivity. The ultimate reasons for the growth of sensitivity are still obscure, but Sheppard's work has shown the importance of sulphur compounds in the gelatine itself. It is believed that complexes are formed which break down to form silver sulphide. Gelatine acts as a medium for holding the silver halides in suspension and as a sensitiser, and it has yet a further function, because it acts as a protective colloid during the attack of the developer. Without it, the grains would be reduced more or less indiscriminately and not in accordance with the light action.

There are two broad theories of development, one of which suggests that the process consists in the deposition of silver upon the latent image from the developer which has first become supersaturated, whilst the second postulates increased adsorption at the points constituting the latent image with consequent increase of developer activity in these regions.

As to the latent image, we are still without definite proof of its nature. Exposure is believed to result in the liberation of electrons from bromine ions. These electrons move about in the crystal lattice, giving rise to the phenomenon of photo-conductance, and when they come into contact with specks of silver or silver sulphide they are held fast—the silver or silver sulphide becomes negatively charged and can then attract silver ions which are also free to move in the crystal lattice. When the nucleus becomes sufficiently large by attachment of silver brought about in this way the grains become developable. Amongst other things, this theory seems to account adequately for the failure of the reciprocity law—that is, for the fact that the photographic effect of a constant product of time and intensity varies according to the level of intensity at which the exposure is made, because at low light intensities as many silver ions may be expected to leave the speck as are attracted to it.

Silver bromide crystals become much more sensitive by the inclusion in them of a small amount of iodide, but the great advance which has been made in emulsion-making technique is largely due to the employment of dye-sensitisers, which, adsorbed to the grain surface, markedly affect the sensitivity, particularly in the region of absorption of the dye. There are other dyestuffs which act as desensitisers and Kendall has put forward a theory which attempts to link behaviour with constitution. By means of dyestuffs, it is now possible to sensitise silver halides right throughout the spectrum and into the infra-red beyond.

The second part of the lecture dealt with the applications of photography to industry, and mention was made of a number of the most important fields in which the photographic plate has contributed to the advancement of knowledge. Astronomy, for example, relies very largely upon it.

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HEAT TREATMENT

PROCESSES — PRACTICE — PLANT

THE number of operations or processes necessary to convert a metal into such a form or condition that it is capable of useful service is considerable. For many purposes it will suffice if metal of suitable composition is cast or formed and subsequently cut to required dimensions, but these operations have an effect on the useful properties, and while it is possible to carry out these operations in such a way that the properties of the metals will fulfil certain conditions of useful service, many metals and alloys are submitted to further operations by which their properties are so influenced that their behaviour in service is greatly improved. Of these operations, the most important is heat-treatment, since it is a vital operation in the fabrication of most metal parts which are required to possess certain specified properties.

In a broad sense, the term heat-treatment embraces all processes which involve heat by which the physical or mechanical properties of metals and alloys are affected; it can therefore be said to be associated with practically all the processes from the ores to the finished metal component. So important is this subject of heat-treatment that Professor Albert Portevin[1] states its study is often of more practical importance than the search for new alloys; further, the useful effect of the addition of new elements is generally entirely dependent on a heat-treatment, without which the result would be of little interest. In this section, however, it is not proposed to deal with the subject in such a broad sense, but to attempt to focus attention more particularly to that class of heat-treatment which, in its narrower sense, is designed to modify the structure and constitution of the metal by controlling the heating and cooling conditions under which changes in the solid state occur. Even this more limited field is very comprehensive and complex, and only a few of the many aspects of the subject can be touched in the limited space of a section of this character.

Ferrous alloys no longer have the distinction of being the only alloys capable or improvement by quenching, hardening and age-hardening. Many non-ferrous alloys which respond similarly to heat-treatment have been discovered, and their field of useful application is increasing as a result, but the ferrous alloys occupy a conspicuous place in the large range of alloys capable of improvement by controlled heating and cooling and in the remarkable variations in properties obtained from different treatments. In both sections great progress has been made in so grading the properties of ferrous and non-ferrous alloys by heat-treatment that a wider range of service conditions is now more successfully met than formerly seemed possible. Processes once used only in the laboratory have become usual in normal production, following the design and application of plant and equipment adapted to workshop conditions.

The process of heat-treatment is used in those alloys which are amenable to such treatment when it is desired to develop their best properties; but all the properties are not improved by a particular process—as a rule a compromise must be effected to develop the most desirable properties in a material for a particular service. The broad principles on which the heat-treatment of alloys is based are indicated in the equilibrium diagrams of the alloys concerned. The heat-treatment of steel, for instance, is dependent on the existence of two forms of iron, one capable of dissolving carbon up to 0·9%, the other of dissolving it only to a very limited extent. The second form, known as Alpha iron, is stable at ordinary temperatures and, in the presence of carbon only, changes on heating into the former, known as Gamma iron, at a temperature of about 730° C. The reverse change takes place on slow cooling, at a slightly lower temperature. In steels containing approximately 0·9% carbon, 730° C. is the only temperature at which a change occurs, but for lower carbon contents there is an "upper" change-point, indicating the minimum temperature to be exceeded before grain refinement can be accomplished. The temperature of the upper change-point varies inversely with the carbon content of the steel, falling from about 900° C. for a carbon content of 0·1% to about 730° C. for 0·9%. The properties of steel vary with, and are dependent upon, the rate of cooling through the change-points, frequently referred to as the critical range; thus to obtain the degree of improvement desirable, the heating and cooling of the material are vital factors.

Considerable attention has been given to the control of heating and cooling in recent years, and great advances have been made. Control is not only concerned with the use of modern appliances developed to assist in maintaining a uniform temperature in the furnace chamber, but in controlling the time and rate of heating, and the atmosphere surrounding the material undergoing treatment. In addition, much more attention is now given to the design of furnaces in order that the temperature of the charge will coincide with that of the furnace chamber. Certain types of heat-treatment furnaces are designed to provide some degree of automatic cooling, but generally this important operation is dependent upon the operator.

In the past it was frequently said that the art of heat-treating did not progress at the same rate as the science of heat-treatment, and the results produced in the shop often fell short of the standard that had been shown to be possible in the laboratory. There will always be a time-lag between the progress achieved in the laboratory and its successful application in the workshop, and the art of heat-treating is not an exception to this general rule, but there is less reason for such charges to-day, because of the facilities for accuracy which modern heat-treatment plant and equipment give, and, where proper equipment is available, it is probable that this time-lag is much less than that in which any other laboratory development is involved.

Much depends upon the equipment installed in the heat-treatment shop; furnaces and equipment of a very high order are available which can reasonably be classed as precision tools. With the aid of these modern appliances, heat-treaters have greatly advanced in their art, but even with the best equipment the increasing demand for materials possessing widely different properties calls for operators of considerable skill and experience. The type of equipment is governed largely by the character and size of work to be processed, but heat-treaters frequently work at a disadvantage in this respect, in comparison with, say, machinists in the machine shop of the same works, where precision tools are installed at great cost to facilitate the accuracy of the machining operations. Similar facilities should be made available to the heat-treater, from which a greater degree of accuracy in treatment would result, and, generally, an improved product.

1. Albert Portevin, "The Phenomena of Quenching and Tempering in Alloys," *Jour. Inst. Metals* 1933, vol. 51, page 315.

...and here really IS

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Temperature Control

– an actual chart from the

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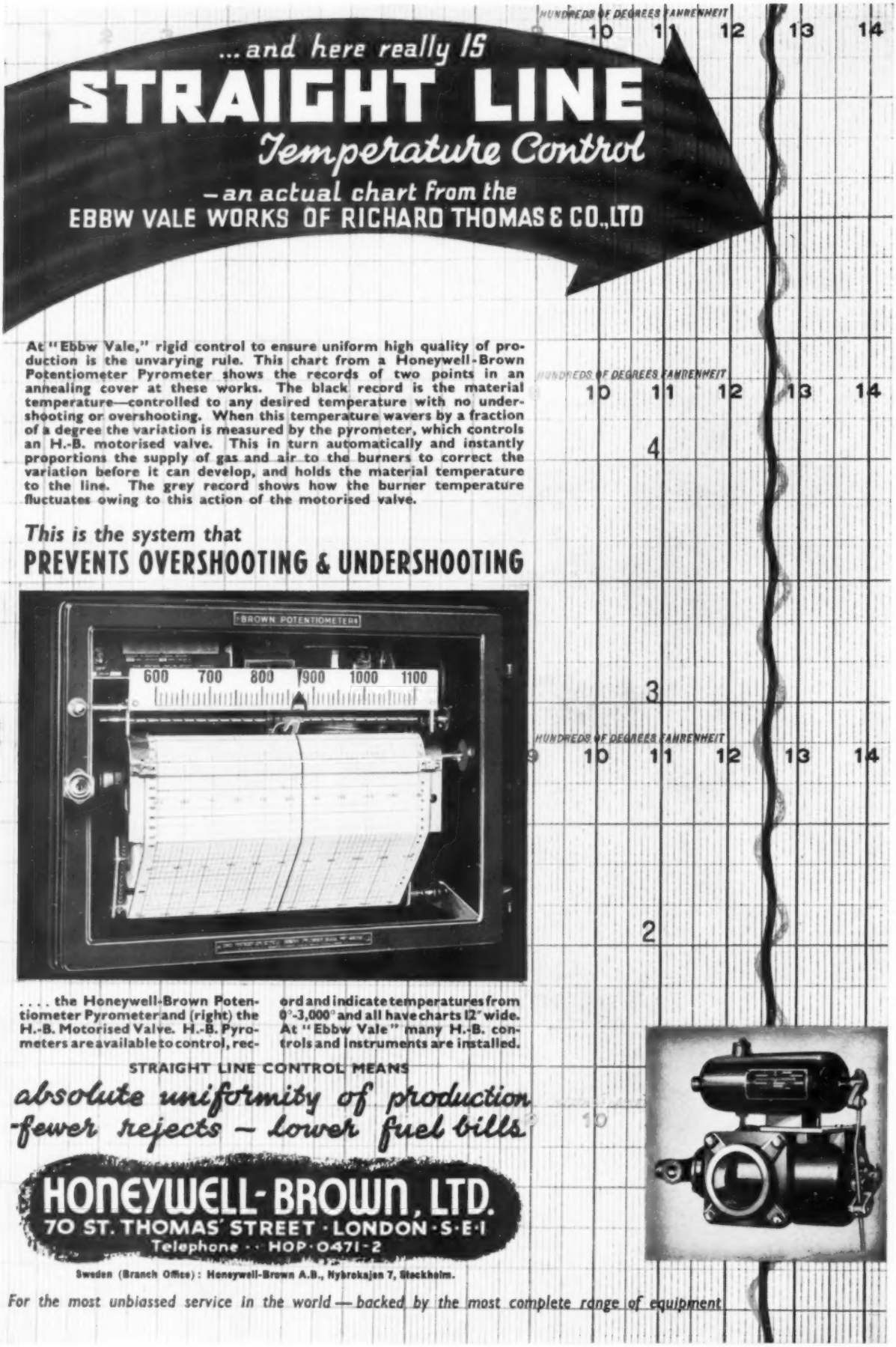

At "Ebbw Vale," rigid control to ensure uniform high quality of production is the unvarying rule. This chart from a Honeywell-Brown Potentiometer Pyrometer shows the records of two points in an annealing cover at these works. The black record is the material temperature—controlled to any desired temperature with no undershooting or overshooting. When this temperature wavers by a fraction of a degree the variation is measured by the pyrometer, which controls an H.-B. motorised valve. This in turn automatically and instantly proportions the supply of gas and air to the burners to correct the variation before it can develop, and holds the material temperature to the line. The grey record shows how the burner temperature fluctuates owing to this action of the motorised valve.

This is the system that

PREVENTS OVERSHOOTING & UNDERSHOOTING

. . . . the Honeywell-Brown Potentiometer Pyrometer and (right) the H.-B. Motorised Valve. H.-B. Pyrometers are available to control, record and indicate temperatures from 0°-3,000° and all have charts 12" wide. At "Ebbw Vale" many H.-B. controls and instruments are installed.

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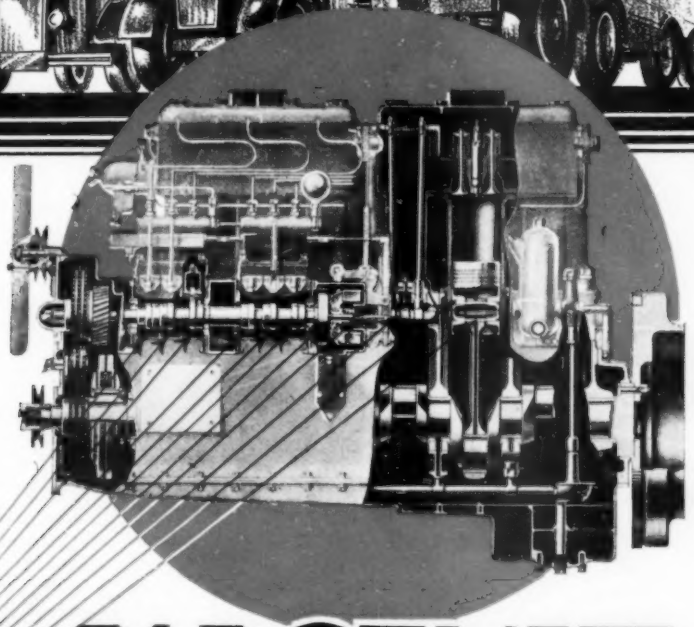

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Kasenit No. 6 Repeating Compound is specially manufactured under most modern control conditions to ensure absolute uniformity. It is the lightest compound marketed for case-hardening; it weighs 20 lbs. per cubic foot and can be used over and over again without the addition of new compound. It contains no coke, leather, anthracite or bone ; every ounce is pure case-hardening material. It is free from dust and is graded to suit customers' requirements.

All Kasenit Compounds are non-inflammable, non-poisonous, and non-explosive.

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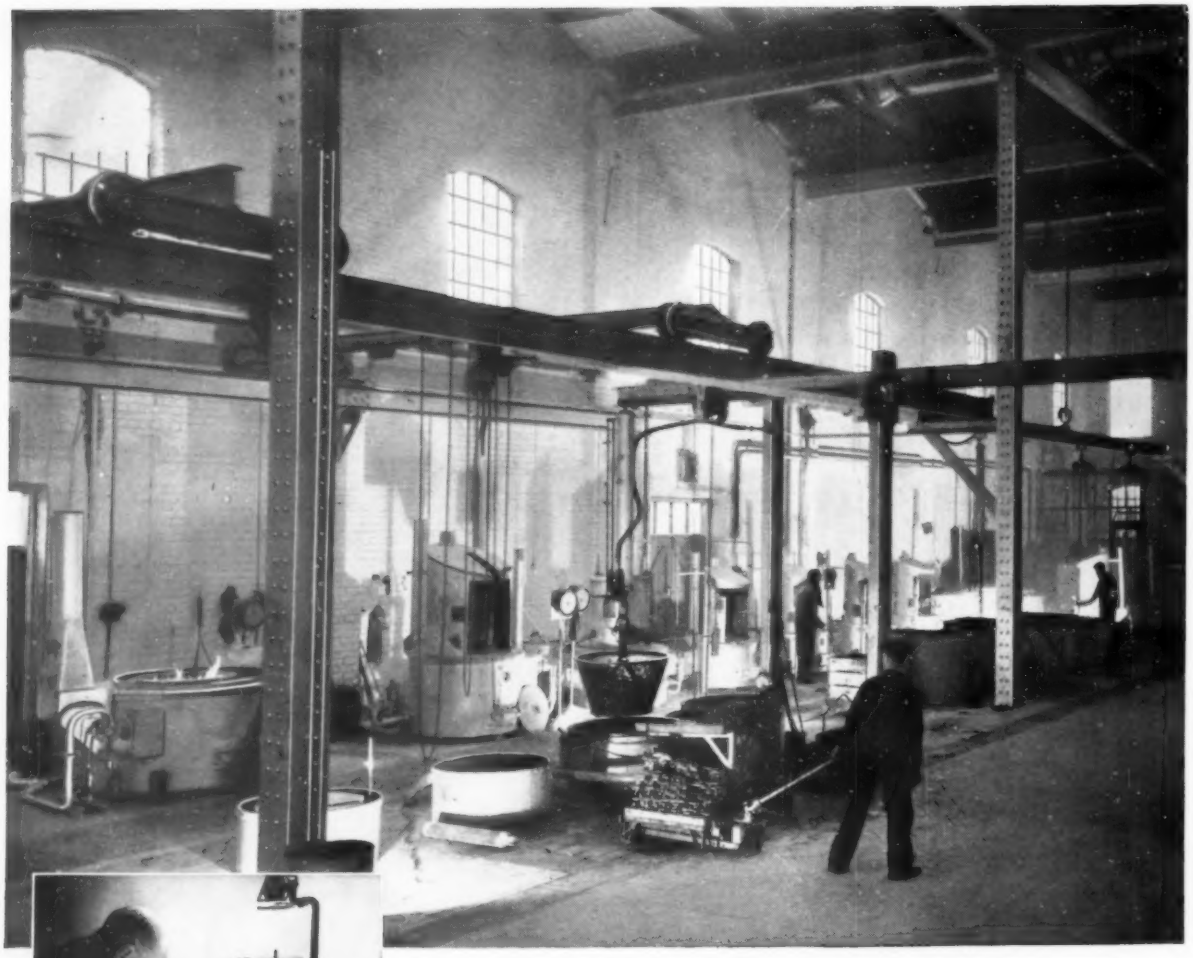

THE 'CASSEL' SERVICE

I.C.I. maintain heat treatment shops in London, Birmingham and Glasgow for the purposes of custom hardening, demonstration of 'Cassel' furnaces and processes, and investigation of customers' problems. Manufacturers whose output does not justify the installation of a hardening shop of their own can have their work treated at any of these stations at reasonable rates. Users of 'Cassel' furnaces and salts are invited to take their problems to the metallurgists of these departments, who will investigate them free of charge. Write for full particulars.

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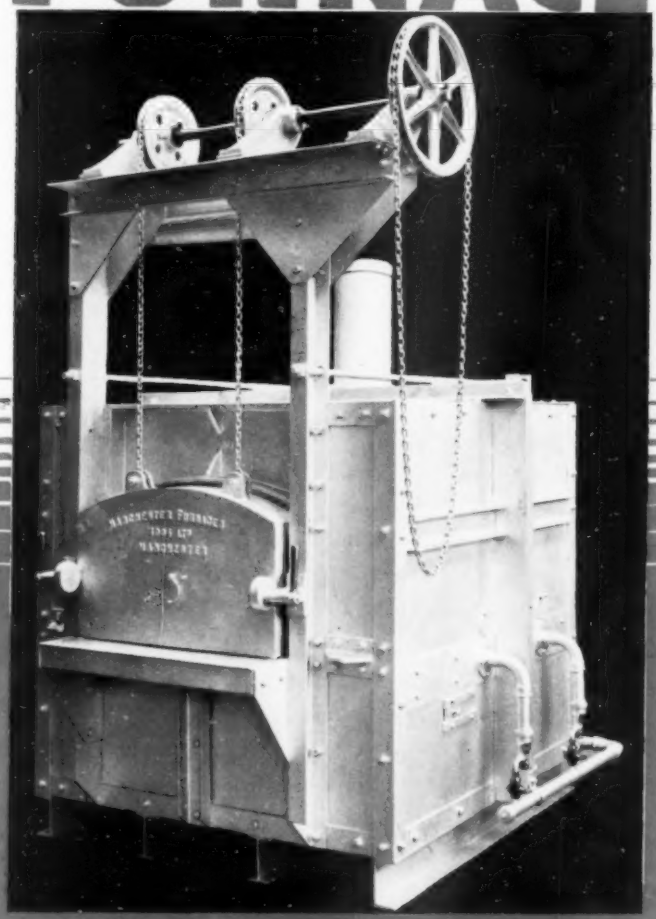
M.89

A typical

MANCHESTER FURNACE



MANCHESTER Furnaces meet all heat treatment requirements, in sizes and types applicable to a wide diversity of purposes. Low fuel consumption, rapid heating and rigid maintenance of temperatures are outstanding features. Advice on standard and individually designed types willingly given.

Illustrated is a gas-fired heat-treatment and reheating furnace for annealing, carburising, normalising, or tempering, with rapid heating to specified temperature and maintenance of temperature within close limits. Economy is assured by complete insulation and effective recuperation. Temperature range of 1200°C. Manual or automatic control, simple in operation.

Recent contracts executed by us include furnaces up to 26' long for precise heat treatment of special steels to critical specifications.

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We have extensive experience of the utilisation of case-hardening boxes and shall be pleased to pass this on to you, together with a copy of the new 'Pireks' Book—full of information about heat-resisting alloys.

FOR ALL HIGH TEMPERATURE PURPOSES

Darwins of Sheffield

DARWINS LTD., FITZWILLIAM WORKS, SHEFFIELD

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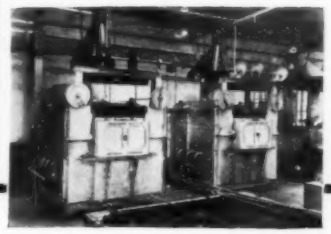

Two "Super" Type Gas-Fired Oven Furnaces installed for reheating purposes by a well-known firm of Automobile Engineers. Furnaces of this type are ideally suited to all classes of heating and heat treatment operations.

Four Fan Recirculated Atmosphere Low Temperature Furnaces installed for the annealing of aluminium alloy sheets. In the foreground may be seen a patent Incandescent electrically-operated charging machine having a reach of 18' 6".

A Gas-Fired Vertical Furnace for normalising and tempering of railway wheels and tyres. Normalising is carried out at 800-850° C., and tempering at 600° C. An excellent example of an Incandescent special-purpose furnace.

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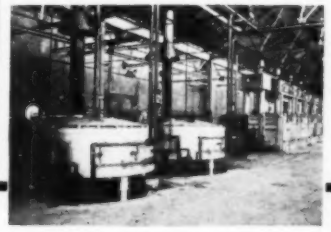
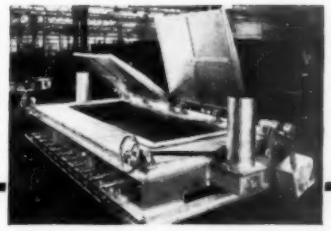
We manufacture furnaces for every purpose and for every industry, from small bench type furnaces to large sheet mill installations covering a range of processes which include annealing, normalising, carburising, hardening, tempering, salt bath treatment, etc. Some idea of the diversity of these manufactures may be gained from the illustrations.

Our Smethwick Works are modern and extensively equipped, incorporating iron, steel and alloy foundries ; machine, erecting, steelwork, welding and sheet metal shops ; physical and research laboratories.

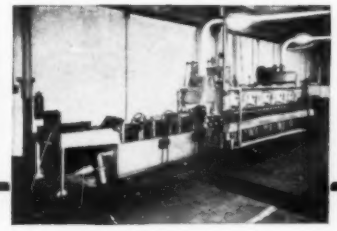
Adequate facilities are provided for the complete manufacture of furnaces and equipment, and our thirty-five years' experience in this sphere places us in a unique position to advise you on your particular problems. May we send further details and catalogues?



Two Rotary Roller Hearth Furnaces, fired by town's gas, for the hardening and tempering of automobile gears. Designed to give a machine-like heat treatment in the most compact floor space, with simple operation and control.



Incandescent Salt Bath Furnace, with a bath 11' × 4' 6" × 1' deep, for the treatment of Duralumin and light alloy parts. Note the simplicity of the door operation giving clear access to bath.



Roller Hearth Furnaces - the very latest practice in continuous heat treatment - suited to all classes of operations. A large number of these furnaces are now in operation in industries throughout the country.

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This bogie type, oil fired furnace has internal dimensions of 19′ 6″ × 10′ 6″ × 6′ 6″ ; Autographic automatic temperature control (up to 1100°C), and is in service in the works of one of the large foundries on the east coast, for the heat treatment of carbon and alloy steel castings from a few pounds to ten tons. It provides rapid and uniform heat control with low oil consumption, and the smooth working bogie simplifies charging and unloading. It has proved specially useful for normalising and quenching treatments.

Long experience in the design of furnaces for all phases of thermal treatment has resulted in the production of furnaces that ensure uniform heat treatment, with every phase controlled within precision limits.

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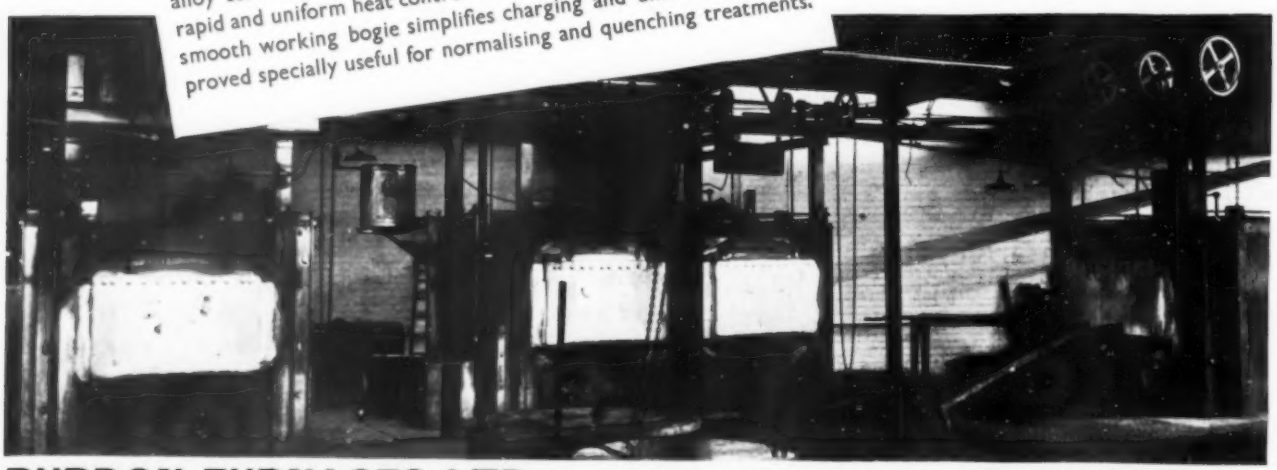
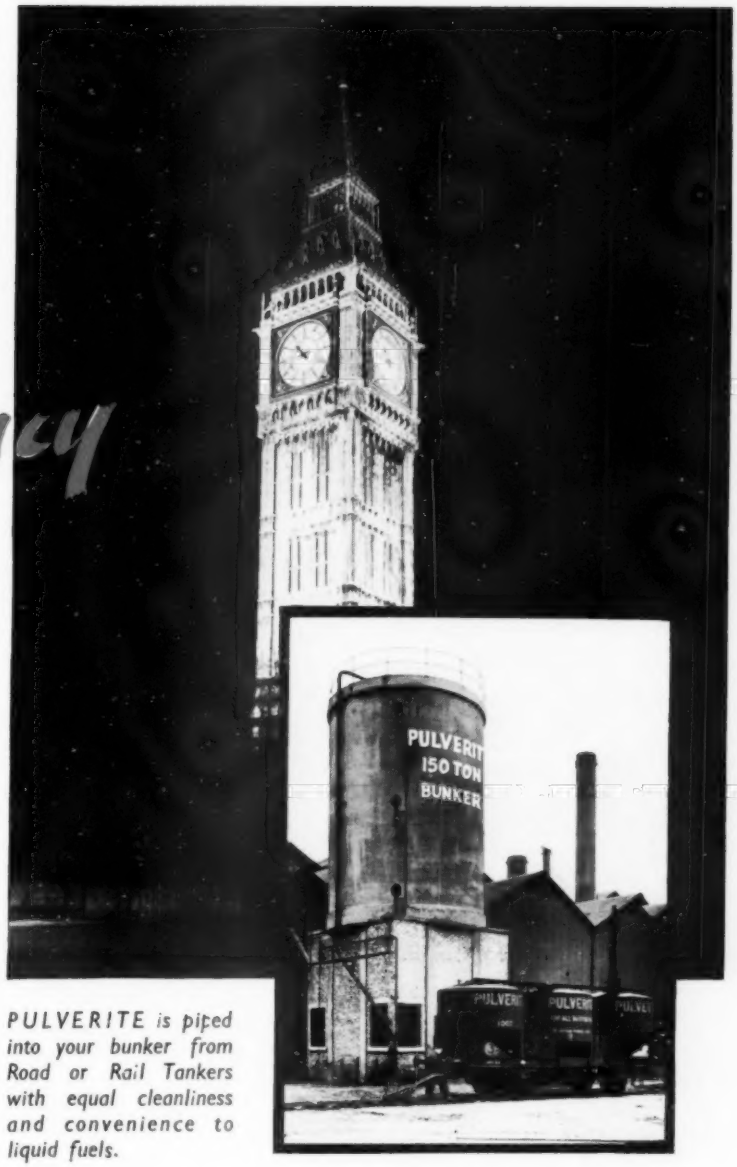
A battery of oil-fired carburising furnaces installed at the works of a large textile machinery manufacturer in Yorkshire.



BURDON FURNACES LTD. *Scottish Industrial Estate, Hillington,* **GLASGOW, S.W.2**



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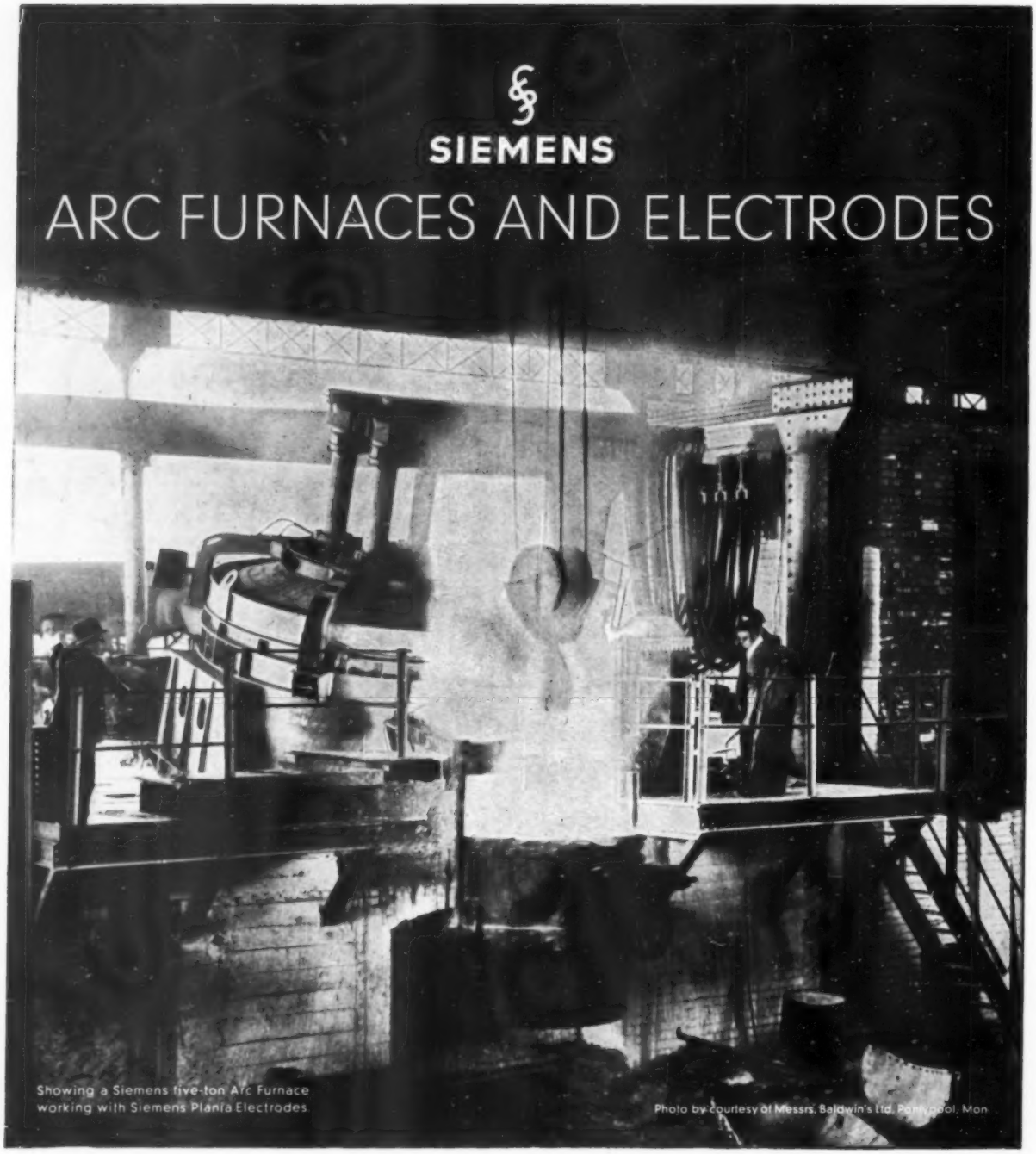
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ARC FURNACES AND ELECTRODES
Showing a Siemens five-ton Arc Furnace working with Siemens Plania Electrodes
Photo by courtesy of Messrs. Baldwin's Ltd. Penyvaal, Mon.

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Just one of the many chapters in metallurgical history where BIRLEC specialist engineers have pioneered, and advanced heat treatment practice to new conceptions of economy and quality.

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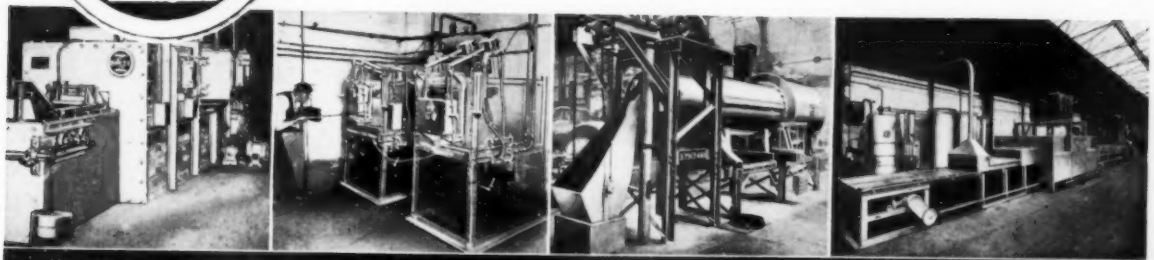

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Our experience covers every type of furnace for heat-treatment—Gas or Oil Fired, or Electric.

Standard or special designs, from simple natural draught furnaces to controlled atmosphere furnaces, automatically maintained within very precise temperature limits. In addition we supply accessories such as charging and handling gear, which minimise time — and heat-losses — enabling you to obtain maximum efficiency and high production schedules.

Let us help you to select the best furnace for the job in hand.

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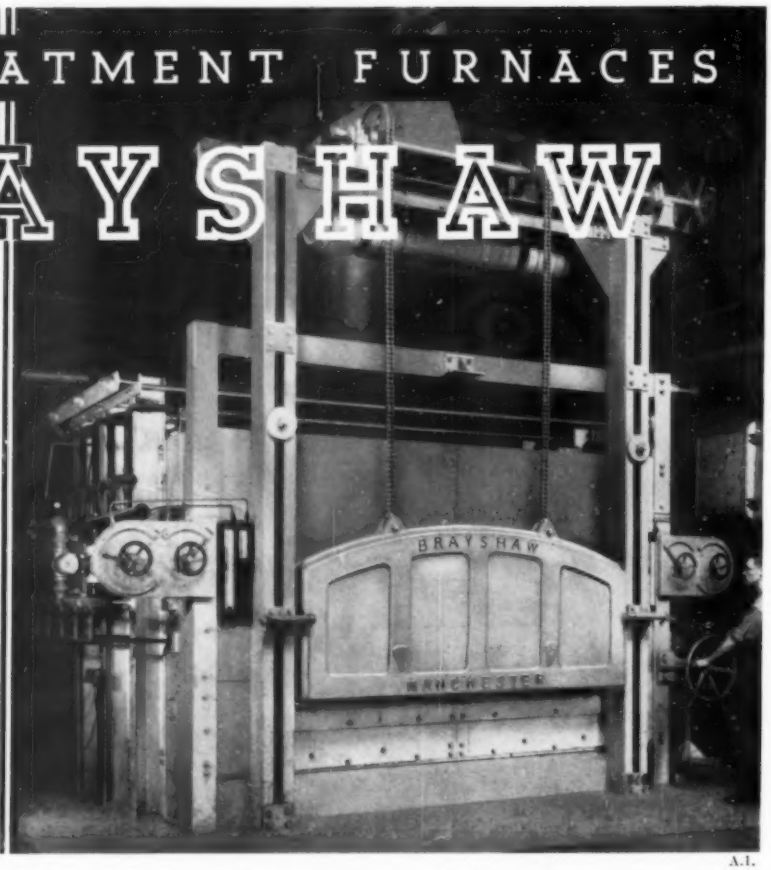

A.1.

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when scientifically burned by Mirrlees-Combustioneer Automatic Stokers . . . .

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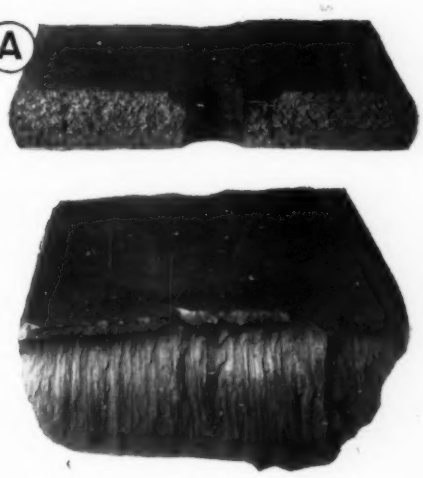
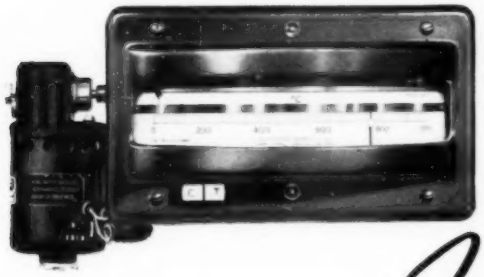
THE PROOF IS IN THE TEST PIECE–



Electroflo Automatic Control of gas-fired furnaces saved a Railway Company considerable sums of money by ensuring that rolling stock leaf springs were correctly heat treated. Fractures, as shown in (a), were frequent before the automatic control was adopted and involved the Company in considerable losses in lay-off periods and repair costs. Additionally, the twenty-five Electroflo Automatic Control Pyrometers reduced the furnace gas consumption by 19%, or more than £1,000 per annum. This installation was made in 1933. Electroflo Automatic Temperature Control is sold on the basis of guaranteed results as determined indisputably by your Laboratory's report on your test piece.



Specify

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AUTOMATIC TEMPERATURE CONTROL

for guaranteed results with the maximum heat economy

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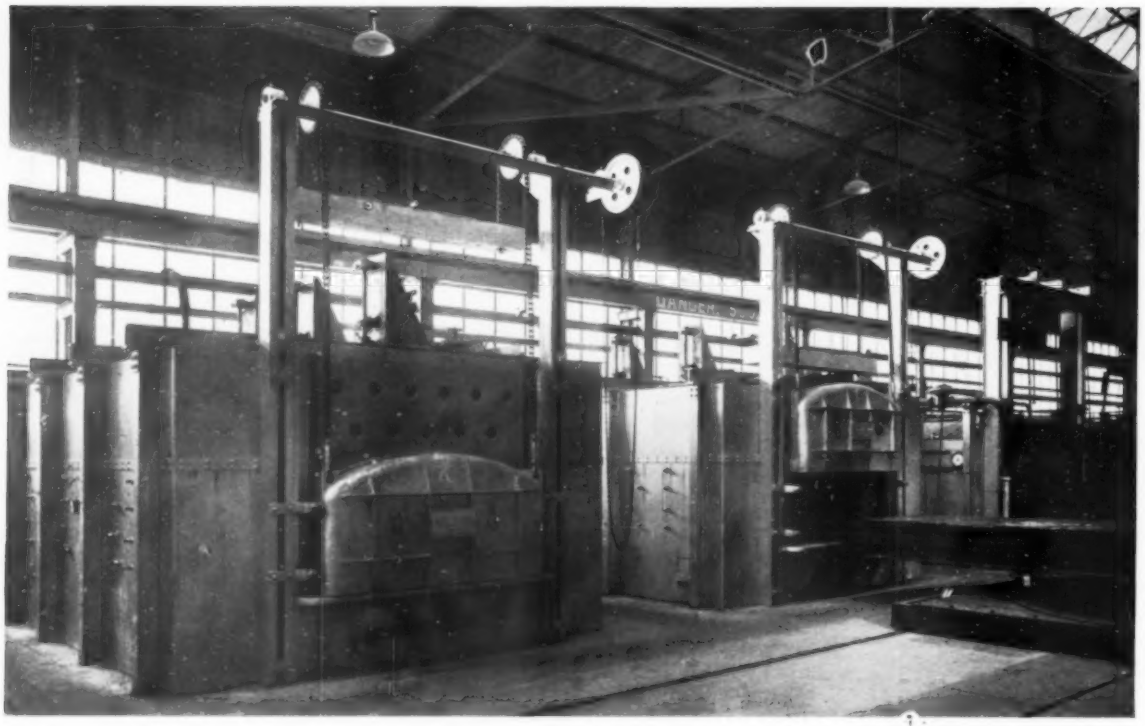

The above illustration shows a battery of Gas Fired Muffle Furnaces for Annealing Light Alloy Sheets.

Reliable results sought in heat-treating practice depend upon the proper combination of the man, the furnace, and the material. Good material is entitled to proper treatment in good furnaces, and both should have the services of good men.

No two cases are alike, and no type of furnace has a monoply on uniformity of heating or economy in operation; for this reason we, as specialists, design heat-treatment furnaces to suit your particular conditions and products; in this way reliable results can be assured, with the utmost economy.

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Typical EFCO vertical forced air circulation furnace for heat treatment of light alloy castings.

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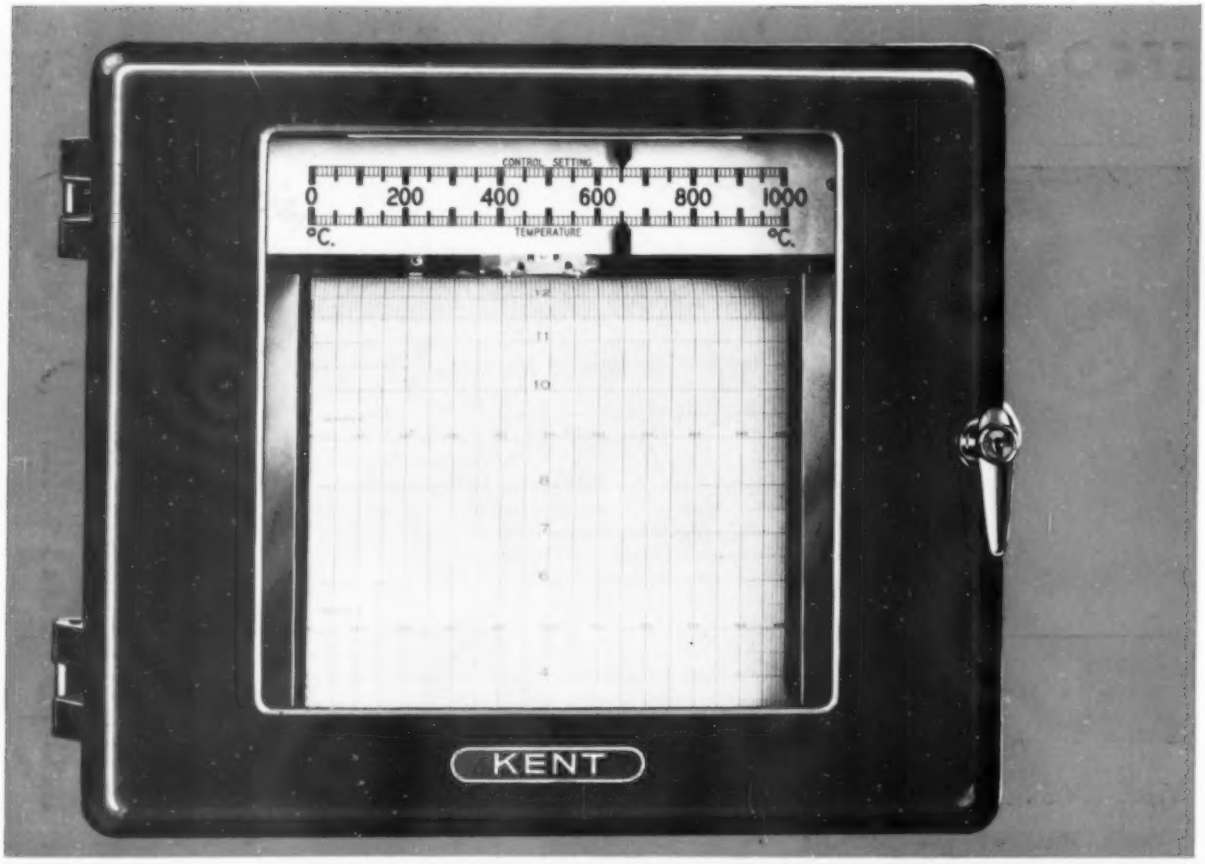

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GEORGE KENT

Controlled Atmospheres in Heat-Treatment Processes

By F. W. Haywood, B.Sc., Ph.D., F.I.C.
(Chief Metallurgist to Messrs. Wild-Barfield Electric Furnaces, Ltd.)

The use of controlled atmospheres in various heat-treatment processes in both ferrous and non-ferrous materials is becoming of increasing importance, and it is now modern practice to introduce an atmosphere of known composition into heat-treatment furnaces to produce the desired results. An account of the various atmospheres available for such processes is given, together with the particular type of furnace best suited to the process. A number of the standard heat-treatments, such as bright annealing, bright brazing and descaling, are cited, together with relevant particulars of specific treatments relating to several materials.

IN practically every heat-treatment process the heated metal or alloy is in contact with an atmosphere with which it may react, the reactions depending upon the nature of the atmosphere and its composition and the nature and temperature of the material undergoing heat-treatment. In the case of electrically heated furnaces, where a controlled atmosphere is not introduced, the natural atmosphere is air; whilst in the case of furnaces heated by the combustion of solid, liquid or gaseous fuels, where the products of combustion are allowed to come into contact with the heated materials, the atmosphere is an exceedingly complex one, consisting of carbon dioxide, carbon monoxide, water vapour, etc.

The main object of introducing a controlled atmosphere into a furnace is to eliminate atmospheric oxygen, so that scaling and tarnishing are avoided and thereby pickling and abrasive cleaning methods are not required. Furthermore, by completely or partially preventing oxidation, a saving in metal is effected which may be quite considerable in the case of expensive materials. Attempts to reduce the scaling produced by oxygen in heat-treatment processes—for example, close annealing—have been practised for a long time, but the introduction of artificial atmospheres of known and controllable composition, working under standard scientific conditions, is of more recent origin.

Atmospheres available for Bright Thermal Treatments

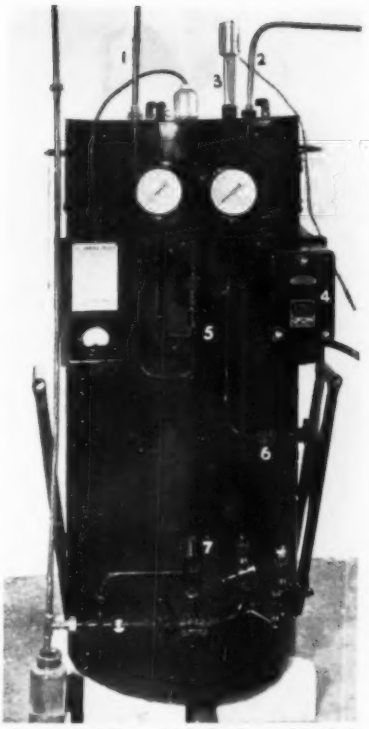
There are numerous atmospheres available to-day for the bright thermal treatment of ferrous and non-ferrous materials, but they may be divided for the sake of simplicity into two main groups, namely:—

(*a*) Atmospheres containing carbonaceous gases.
(*b*) Atmospheres which do not contain carbonaceous gases.

Concerning the former category, it is safe to say that at the present juncture the major proportion of materials, particularly ferrous materials, are heat-treated in atmospheres derived from carbon compounds. This is particularly so in the U.S.A., where large quantities of natural gases are available at very little cost. In this country, however, attention has been confined very largely to a relatively small number of compounds as follows:—

Burnt Hydrocarbons.—A number of hydrocarbons, which are by-products from the oil refineries, are available for the production of protective atmospheres, those of major importance being butane and propane. By the controlled combustion of these gases with air, an atmosphere may be produced which consists essentially of nitrogen, hydrogen, carbon dioxide, carbon monoxide, and water vapour. For example, the composition of burnt butane may vary over reasonably wide limits as given below:—

$CO = 12\text{–}1\%$; $H_2 = 10\text{–}1\%$; $CO_2 = 6\text{–}15\%$; N_2 = balance.



1. Ammonia gas inlet.
2. Cracked gas outlet.
3. Thermostat.
4. Contactor.
5. Pressure regulating valve.
6. Fine adjustment valve.
7. Pressure valve.

By courtesy of Messrs. I.C.I. (Fertilizer and Synthetic Products), Ltd.

Fig. 1.—I.C.I. Ammonia cracker plant.

Unless suitable apparatus is installed, the burnt butane will also contain water vapour and sulphur compounds; the former can be removed by means of driers, and the latter by means of sulphur removal apparatus. The question of sulphur removal is of vital importance, particularly in electric furnaces, as sulphur compounds are very prone to attack nickel chromium heating elements, and also muffles of like materials.

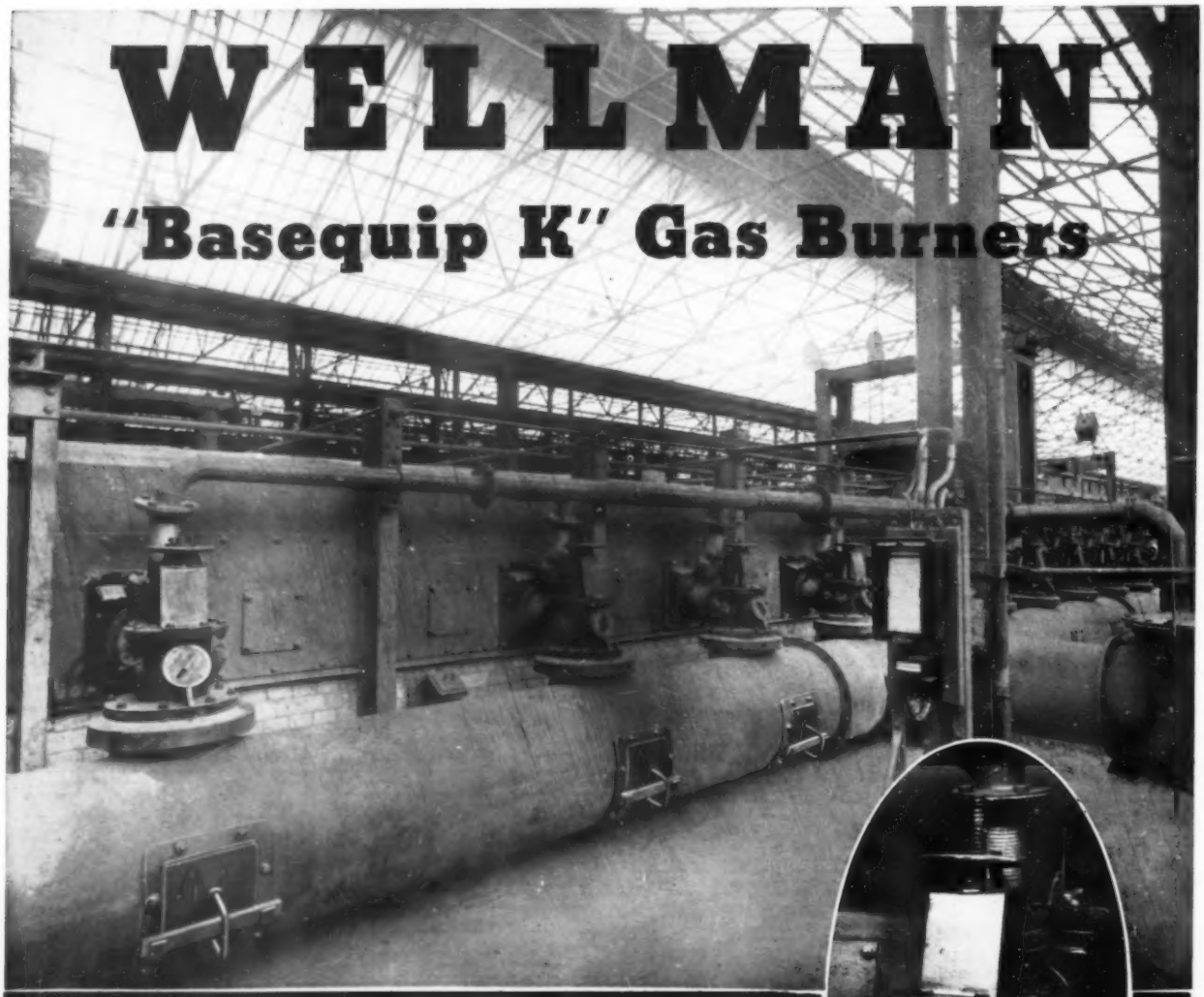
In recent years coal gas has very largely superseded bottled hydrocarbon gases, as it is reasonably cheap and so very easy of access, being available "on tap" in almost every manufacturer's works. Sometimes in a specialised number of cases raw coal gas is used for a particular heat-treatment process, but generally the coal gas is burnt with a controlled amount of air to give an atmosphere consisting largely of CO, CO_2, H_2, and N_2, together with water vapour. In the case of almost every coal-gas burner, some form of sulphur removal train is incorporated, either before the combustion chamber or after it, as no supplies of town's gas are available which do not contain sulphur compounds in some form or other, and it is usual to employ bog-iron ore boxes, activated charcoal, etc., for this purpose.

Solid Fuels.—By the controlled combustion of solid fuels, such as coal, coke, etc., used in general metallurgical practice, there are made available large quantities of various gases, such as producer gas, blast-furnace gas, water gas, and coke-oven gas, which may be used to provide a protective atmosphere for general heat-treatment purposes. It is generally necessary to reform or purify these gases before introduction into furnaces, but even so, the cost of such gases is so extremely low that where the gases are available, it is more economic to instal purification plant than a special complete atmosphere plant. In the annealing of steel sheets in large batch furnace installations, it is quite common practice not only to heat the furnaces with waste gases, but also to introduce such gases into the annealing boxes to prevent oxidation and to give a bright sheet.

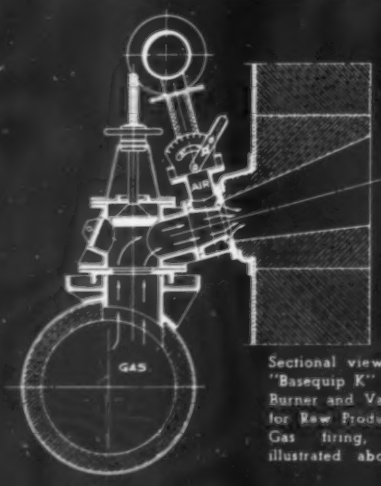
Charcoal, as a source of raw material, may be used for the production of a protective atmosphere which is eminently suitable for use in ferrous heat-treatment processes, particularly where the question of decarburisation is vital. In

WELLMAN

"Basequip K" Gas Burners



Dual Purpose Tube Furnace (Re-heating and Annealing), at the Dumbarton Works of Messrs. Babcock & Wilcox Ltd., fired with eleven "Basequip K" Gas Burners. Fuel-Raw Producer Gas.



Sectional view of "Basequip K" Gas Burner and Valve for Raw Producer Gas firing, as illustrated above.

The "Basequip K" Gas Burner is of simple yet robust construction and is explosion-proof. The gas passes through a large central orifice at low velocity while the air is introduced at high velocity through a series of tangentially drilled holes placed in a ring round the gas nozzle. This ensures thorough mixing of gas and air, with the result that the combustion is complete within the burner block, evidenced by the absence of visible flame in the furnace.

THE WELLMAN SMITH OWEN ENGINEERING CORPORATION. LTD
VICTORIA STATION HOUSE, LONDON, S.W.1. WORKS: DARLASTON, SOUTH STAFFS

order to produce an atmosphere consisting on entry to a furnace of CO and N_2, it is essential to devolatilise the charcoal before combustion and also to dry the air led to the combustion chamber. If this is not done then the atmosphere produced by burning the charcoal will contain carbon dioxide, water vapour, and traces of hydrocarbons. A charcoal burner has recently been manufactured which provides a protective atmosphere capable of giving entire absence of decarburisation on high carbon steels when subjected to the normal temperatures used for bright hardening.

Most of the atmospheres mentioned so far possess the following characteristics :—

(i) They contain carbon monoxide and carbon dioxide, which at certain temperatures may react to produce carbon deposition ; furthermore at one temperature the gas mixture may be reducing and at another oxidising.

(ii) The gas mixtures are of a toxic nature, and care must be taken to lead away such gases to atmosphere.

(iii) They are explosive.

(iv) They quite often contain traces of free oxygen, which may have a detrimental action on certain metals and alloys.

(v) Unless carefully dried, they contain water vapour which can be extremely harmful in certain heat-treatments.

(vi) Quite often they contain sulphur compounds which exert a deleterious action on muffles and nickel chromium resister elements.

(vii) They are quite easily produced, and are extremely cheap to use, and particularly in the case of burnt town's gas atmosphere the raw material is easily available.

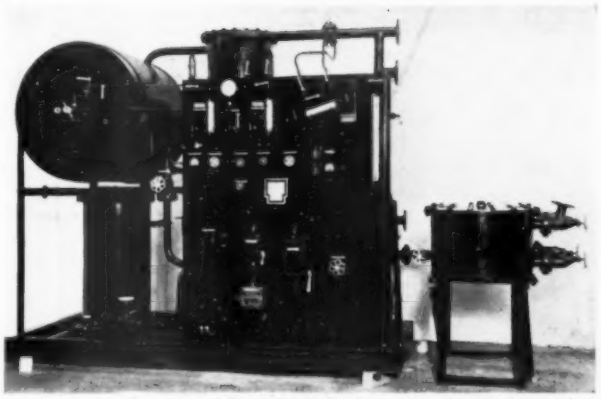
Atmospheres not containing Carbonaceous Gases

The number of commercially applicable controlled atmospheres derived from sources not containing carbon compounds is more limited, but these atmospheres have many points to recommend them. It is not proposed to deal with atmospheres, such as chlorine and sulphur dioxide, which are used very largely in the course of manufacture of magnesium and light alloys, but rather to those which consist essentially of mixtures of nitrogen and hydrogen.

Nitrogen and hydrogen as compressed gases in cylinders find a limited application in heat-treatment processes in industry, owing largely to the cost of such gases, which is dependent upon a number of factors, such as hire and depreciation on cylinders, freightage, and distance from the main source of supply. Furthermore, if hydrogen of extreme purity is desired, then this can be supplied as a compressed gas, but at excess cost, due to the removal of traces of oxygen by chemical means. Quite often such a gas, whilst being relatively free from free oxygen, contains traces of water vapour which may be extremely injurious in certain cases.

Hydrogen may also be produced in reasonably large quantities in industry by the electrolysis of water, but the use of such hydrogen, after suitable purification, is only rendered an economic proposition when the oxygen, also produced by the electrolytic cell, can be used continuously. An example of the application of cell hydrogen is in the degassing of radio valve parts. Hydrogen may also be available in certain chemical processes as a by-product, but the number of cases where such hydrogen—which requires purification before use—finds application is extremely limited.

A particularly convenient raw material which can provide mixtures of nitrogen and hydrogen is, however, available in the form of anhydrous ammonia. This is normally a gas which, when compressed into cylinders at normal temperatures under a pressure of some 80 lb. per sq. in., is a liquid. Furthermore, anhydrous ammonia



By courtesy of Messrs. I.C.I. (Fertilizer and Synthetic Products), Ltd.

Fig. 2.—I.C.I. regenerative ammonia burner plant.

is an extremely pure raw material, having a purity guaranteed by the manufacturers of at least 99·98% ; is readily available in large quantities and in various sizes of cylinders, and is reasonably cheap in price.

The atmospheres which are produced from anhydrous ammonia are as follows :—

Cracked Ammonia.—Cracked ammonia or ammonia cracker gas is produced by the almost complete " cracking " or dissociation of anhydrous ammonia into its constituent elements, hydrogen and nitrogen, according to the equation :

$$2\,NH_3 \rightleftharpoons N_2 + 3H_2$$

This reaction, which is endothermic, requires heat and also the use of a suitable catalyst, two volumes of ammonia giving four volumes of a mixture consisting essentially of 75% hydrogen and 25% nitrogen. The necessary apparatus for the production of such an atmosphere is termed an ammonia cracker, an illustration of an I.C.I. ammonia cracker being shown in Fig. 1. This plant is small, of compact design, and requires the minimum of skilled attention, being fully automatic in operation. A controlled supply of anhydrous ammonia from cylinders is led to the cracker, where it is dissociated or " cracked " by passage over a suitable catalyst maintained at a temperature not in excess of 550° C. by means of a radiant type of electric heater. The cracked gas leaving the ammonia cracker requires no purification and can be led straight to the heat-treatment furnace or other plant. The properties of cracked ammonia are as follows :—

(i) It consists essentially of a mixture of 75% hydrogen and 25% nitrogen with not more than 0·1% by volume of free ammonia. For most metallurgical heat-treatment purposes, which will be outlined later, this small percentage of free ammonia is not deleterious, but where necessary this may be removed completely.

(ii) The gas is entirely free from all traces of oxygen and water vapour, being of far greater technical purity than bottled or electrolytic hydrogen.

(iii) The gas is very much cheaper than electrolytic hydrogen or cylinder hydrogen when all incidental charges are taken into account.

(iv) The gas is naturally of an explosive nature, but when properly applied to furnaces specifically designed for the use of protective atmospheres no difficulties whatsoever are encountered.

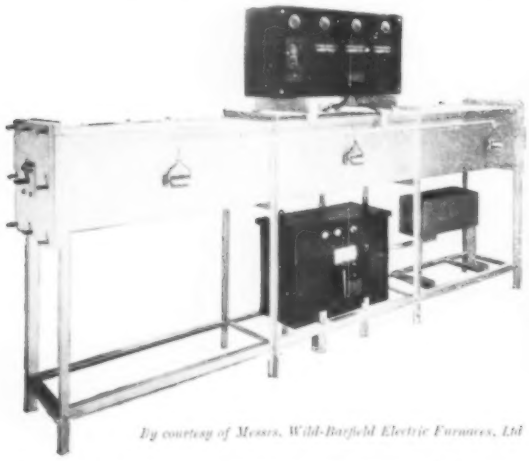
(v) The " all-in " cost of cracked ammonia varies between 13s. 6d. and 20s. per 1,000 cub. ft. of gas, dependent upon the size of ammonia cylinder used.

Burnt Ammonia.—By the controlled combustion of cracked ammonia with air, a gas, termed burnt ammonia or ammonia burner gas, results, which consists essentially of nitrogen admixed with hydrogen. Thus :—

$$2NH_3 = N_2 + 3H_2$$
$$N_2 + 3H_2 + 3/2(4N_2 + O_2) = 3H_2O + 7N_2$$

If complete combustion of the hydrogen of the cracked ammonia takes place, then two volumes of ammonia, giving four volumes of cracked ammonia, produce seven volumes of nitrogen and three volumes of water vapour which is condensed out. It will be seen that if incomplete combustion takes place, then a mixture of nitrogen with hydrogen results. In commercial plants, termed ammonia burners, it is usual to control the combustion so that the resulting gas mixture varies between the following limits:—

Nitrogen, 90–99%; hydrogen, 10–1%



By courtesy of Messrs. Wild-Barfield Electric Furnaces, Ltd.

Fig. 3.—Continuous pusher-type copper-brazing furnace, using a cracked ammonia atmosphere.

It is generally admitted that the ideal atmosphere for most bright heat-treatments in both ferrous and non-ferrous metallurgy is nitrogen admixed with a small percentage of hydrogen: it being preferable to have such a mixture entirely free from water vapour and free oxygen. Such an atmosphere is produced by the ammonia burner, and this atmosphere may be used for the bright thermal treatment of practically every metal and alloy. The gas possesses the properties of being non-toxic: non-inflammable and non-explosive, entire absence of oxygen and entire absence of water vapour (if desired): freedom from sulphur and carbon compounds: extreme purity and constancy of analysis: and does not react at temperature with metals and alloys undergoing heat-treatment. Unfortunately, there is one factor which militates against its general use—namely, its much higher cost than that of protective atmospheres derived from carbonaceous gases; this figure being 7s. 6d. to 10s. per 1,000 cub. ft. of gas.

Research work was carried out by Messrs. Imperial Chemical Industries, Ltd., with a view to reducing the cost of burnt ammonia to a figure as low or lower than that of atmospheres derived from other sources, so making it possible to treat all materials, but particularly the cheaper ferrous materials, at an economic figure. This resulted in the I.C.I. patented regenerative ammonia burner, in which the principles of recirculation and regeneration are used. The broad principles underlying this type of burner are that the protective atmosphere after being used in, say, a batch or a continuous furnace and now containing small percentages of oxygen, instead of being allowed to purge out to atmosphere and so be lost, is collected in a suitable capacity vessel and by means of a blower is led back to the burner; where the now contaminated atmosphere is regenerated by heating it up and passing it over suitable catalysts. Thus the atmosphere is used over and over again, and it has been found possible by this means to reduce the cost generally to the order of 9d. to 1s. per 1,000 cub. ft. of recirculated atmosphere; in special cases down to a figure of 6d. to 8d. per 1,000 cub. ft. This latter figure is of the same order as the cost of atmospheres derived from burnt coal gas.

Fig. 2 shows a photograph of a typical I.C.I. regenerative ammonia burner plant. It will be appreciated that if a perfectly dry atmosphere of burnt ammonia is required, then it will be necessary to dry the gas after combustion. This has been accomplished with entire satisfaction in regenerative type driers using a drying medium, such as silica gel or activated alumina.

Types of Electric Furnace used in Bright Thermal Treatments

One of the early difficulties in connection with the application of protective atmospheres to electric furnaces was to apply the atmospheres to furnaces which were not

(By courtesy of Messrs. G. W. B. Electric Furnaces Ltd.)

Fig. 4.—Batch type bright annealing furnace for steel bars using a protective atmosphere provided by burnt coal gas.

designed specifically for such work, and it may be taken as axiomatic that the best results can only be obtained when the furnace, no matter what type or how it is heated, has been designed specially for use with a protective gas atmosphere.

Batch Furnaces.—Some of the first furnaces in this country to be used with protective atmospheres were batch furnaces of the bell-base or top-hat type, where a series of sealed containers are used in conjunction with a single furnace or where multiples of such a system are used. The work container was sealed with either sand, chromite or a liquid seal, such as oil or water, and not infrequently a combination of both types of seal was employed. It is now common practice in such furnaces to incorporate a fan which, whilst giving forced circulation of the atmosphere, assists materially in the uniformity of heating and cooling of the charge of work undergoing heat-treatment.

Other types of batch furnace include the retort or pot type with special seals: batch furnaces with interior heating elements and rectangular box-type furnaces.

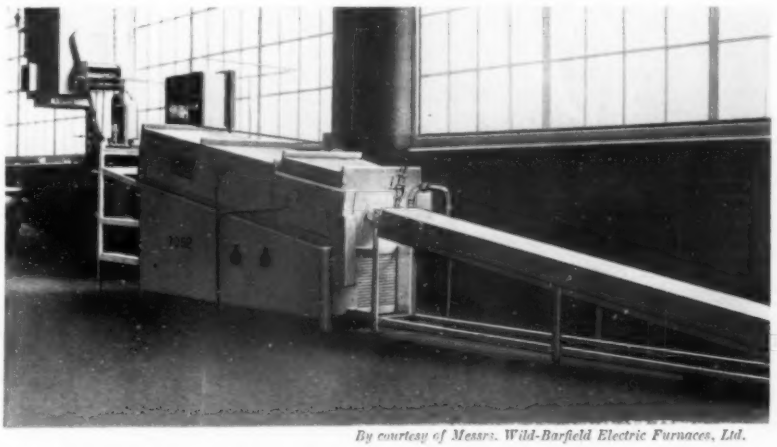
In batch bright-treatment furnaces the work is loaded into the work basket and the work container, bell, or hood placed over the work. The air in the bell is now removed by purging out with the protective atmosphere being used, and when completely purged the furnace is lowered over the bell and the heating cycle commenced. It is customary to keep a flow of gas to the bells during the whole cycle, and although not absolutely essential during heating and soaking of the charge, it is better to do so, and essential during cooling. After the charge has been heated for the requisite period, the furnace is removed and placed over another charge which has been previously purged and the cycle of operations repeated. The work is only removed from the container when it has attained a temperature at which oxidation will not occur on exposure of the work to the atmosphere.

In the case of a batch furnace installation working in conjunction with an I.C.I. regenerative ammonia burner, the gas after purging through a fresh charge of work is passed either to a gas-holder or large-capacity vessel, from which it is withdrawn to the burner for regeneration and recirculation through the system again.

Concerning batch furnaces proper, where a metal retort bell or base is not used, such as reheating furnaces, high-speed steel hardening and preheating furnaces, the application of a protective atmosphere presents greater difficulties, but nevertheless these are gradually being overcome and a better product obtained.

Continuous Furnaces.—Continuous furnaces of the conveyer type, employing mesh belts, continuous strip ; pusher types ; pan-conveyer types ; rotary drum ; vertical types for strip ; special horizontal types ; rotary hearth types ; strand annealing types, etc., are used in conjunction with protective atmospheres for the bright thermal treatment of ferrous and non-ferrous metals and alloys with very satisfactory results. Sometimes it is essential to use a metal muffle through the heating chamber, to avoid either contamination of the heating elements with the atmosphere, or the contamination of the work being treated from traces of oxygen or water vapour given off from the refractory lining material of the heating chamber ; but it is safe to say that with rare exceptions it is possible by a suitable combination of atmosphere and design of continuous furnace to bright heat-treat almost any standard engineering metal or alloy. When using atmospheres which contain carbon monoxide, it is advisable to provide cowls at the entrance and exit ducts of the furnace to remove the obnoxious gases and also to provide, where possible, suitable sealing devices to cut down the volume of atmosphere necessary to prevent the ingress of atmospheric oxygen.

On continuous furnaces working in conjunction with regenerated ammonia burner gas, it is necessary to provide for rather longer extensions of the entrance and exit ducts in order to allow for gas withdrawal points and sealing devices. A number of furnaces working in conjunction with various types of controlled atmospheres are shown in the accompanying illustrations, Figs. 3, 4, 5 and 6, while other examples are shown marked elsewhere in this section.



By courtesy of Messrs. Wild-Barfield Electric Furnaces, Ltd.

Fig. 6.—Continuous-strip bright hardening furnace, using water-cooled quenching dies provided with an atmosphere of coal-gas.

By courtesy of Messrs. Wild Barfield Electric Furnaces, Ltd.

Fig. 5.—Multiple bell brazing furnace for semi-continuous brazing with silver solders in a cracked ammonia atmosphere.

Processes where Controlled Atmospheres are used

The application of controlled atmospheres in metallurgical operations is increasing from day to day, and it is not within the scope of this present article to list them all. The following list gives a number of the more important processes which are now well established :—

(i) Bright annealing, stress relieving, normalising, degassing.
(ii) Bright hardening.
(iii) Bright tempering.
(iv) Descaling of hot-rolled materials.
(v) Bright brazing with copper or silver solders.
(vi) Reduction of metallic oxides and reduction processes.

(i) *Bright Annealing.*—If it is desired to obtain a perfectly bright finish after annealing on most metals and alloys, it will be found almost essential to take some measure of precaution to remove the lubricants left on articles after the last operation, such as rolling, drawing, pressing, etc. In the case of oils this is not difficult, as modern degreasing methods are available which will remove all traces of oily lubricants at a reasonable cost ; but where soaps and fats are used it is often only by liquid washing methods that these may be removed. Furthermore, the products should not only be free from lubricants, but bright before annealing. Very slight tarnishing due to oxides can be dealt with satisfactorily, but heavy oxide coatings, as in the case of hot-rolled steel strip, will result after descaling in a whitish-grey matte surface—that is, a reduced surface.

Turning to the bright annealing of the non-ferrous metals and alloys ; exclusive of the light metals and alloys, it is found that copper in its various forms of strip, wire, rod, sections, pressings, etc., can be satisfactorily bright annealed in atmospheres derived from gases containing carbon—care being taken to ensure removal of sulphur from the raw or burnt products—over a wide range of temperature extending from 250°–600° C. It is not advisable, however, to treat copper, particularly of the tough pitch variety, in atmospheres containing more than about 10% of hydrogen, otherwise hydrogen embrittlement ensues, particularly at temperatures over about 400° C. Copper can be bright annealed equally well in batch or continuous furnaces, the former being used for coils of wire and strip, and the latter for cut lengths of strip, tubes, and sections.

Copper alloys, such as the phosphor bronzes, are more difficult to bright anneal owing largely to the phenomenon of "sticking," and perfect results are not obtained in carbonaceous atmospheres. Strand annealing furnaces, using as an atmosphere cracked ammonia, offer the best solution to the problem of sticking with the 99/1, 99/5, and 93/7 phosphor bronzes.

The copper-zinc alloys—namely, the brasses ranging in composition from roughly 90/10 to 60/40, are among some of the most difficult alloys to bright anneal. The difficulty increases with the increase in zinc concentration, and the best results are obtained by annealing the brasses, after careful degreasing, in cracked ammonia or dried burnt

ammonia. Also, wherever possible, continuous furnaces are indicated, particularly for fine wire and strip.

Nickel, nickel-copper alloys and nickel-iron alloys are reasonably easy to bright anneal in atmospheres derived from carbon-containing gases, but care must be taken to remove traces of sulphur. Good results are obtained in atmospheres derived from anhydrous ammonia, and not infrequently cracked ammonia is used for the degassing of nickel parts for radio valves and the like. Continuous furnaces are more frequently employed for the bright annealing of nickel and nickel-copper alloys.

The nickel silvers, containing copper, nickel, and zinc, present some difficulty owing to the zinc concentration, and whilst reasonably satisfactory results may be obtained using dried burnt hydrocarbon gases, a better finish is obtained in dried nitrogen-hydrogen atmospheres, continuous furnaces generally being employed for heat-treatment.

With regard to nickel-chromium and nickel-chromium-iron alloys, these are difficult to bright anneal perfectly, and satisfactory results can only be obtained in cracked or burnt ammonia atmospheres. Batch, continuous, or strand annealing furnaces are used for the bright annealing of this class of alloys.

Regarding the bright annealing of ferrous materials, a number of factors must be borne in mind which are rather different from non-ferrous metal treatments, such as the relatively cheap cost of the ordinary ferrous materials and the large quantities to be dealt with. This raises such points as metal cleaning and degreasing prior to annealing, which can only be employed when the whole process of cleaning and bright annealing is more economic than straight annealing, followed by pickling and washing methods. As mentioned previously, large tonnages of mild steel are satisfactorily bright annealed in atmospheres of reformed coke-oven gas, blast-furnace gases, and producer gases. Atmospheres derived from burnt coal gas are quite satisfactory for mild and low-carbon steels, and the type of furnace is entirely dependent upon the size and shape of the material undergoing treatment. Sheets of mild steel are often annealed in packs in continuous furnaces, whereas similar sheets are bright normalised in continuous roller hearth or other type continuous furnaces.

With plain carbon steels, where the carbon content is above approximately 0·3%, greater care must be taken regarding the protective atmosphere to ensure that decarburisation does not occur. The gases which produce decarburisation at the normal temperatures for the heat-treatment of plain carbon steels, are hydrogen, water vapour, carbon dioxide, and free oxygen.

A considerable amount of research work has been carried out concerning the effect of hydrogen on the decarburisation of steels at ordinary pressures, but it is now fairly certain that absolutely dry hydrogen exerts but little effect compared with hydrogen containing quantities of water vapour. The other three gases enumerated—namely, water vapour, carbon dioxide, and free oxygen—besides being very effective gases with regard to decarburisation, also produce scaling, and although in certain cases scaling may retard decarburisation, are definitely injurious to the surface of the steel. Thus if a controlled or protective atmosphere derived from carbonaceous gases is used for the bright annealing of carbon steels, careful attention must be paid to the H_2/H_2O, CO/CO_2, and H_2/CH_4 ratios, and one of the first and most obvious things to do is to dry the burnt gases as effectively as possible. A further prior state is the removal of free oxygen and the elimination of all sulphur compounds. Hence the controlling gas reaction is thus the CO/CO_2 ratio, and this equilibrium ratio varies for each particular temperature. Thus it will be seen that the choice of really effective atmospheres for the bright annealing of plain carbon steels, so that after treatment they may be free from decarburisation, is limited to purified and dried gases consisting essentially of CO_2, CO, and N_2; dried burnt ammonia of a composition approximately 95% N_2 and 5% H_2; and dried charcoal gas consisting essentially of CO and N_2.

The type of furnace used for such heat-treatments is entirely dependent upon the size and shape of the material, batch furnaces for sheets and coils of strip and wire, and continuous furnaces for rods, tubes, sections, cut lengths of strip, etc.

Alloy steels containing low percentages of alloying elements, such as nickel, chromium, manganese, vanadium, etc., can be bright annealed with satisfaction in atmospheres suitable for plain carbon steels; but when the alloying elements render the steel austenitic, as in the case of the 18/8 nickel-chromium steels and like steels, then it is almost impossible to obtain a satisfactory finish in any atmosphere other than that derived from anhydrous ammonia. Cracked ammonia and dry burnt ammonia are satisfactory for this purpose, and for perfect results it is necessary to resort to degreasing of the materials before annealing. The extreme difficulty with regard to the bright annealing of the nickel-chromium austenitic steels is due largely to the ease and rapidity with which the chromium in the steels combines at heat-treatment temperatures, with small traces of oxygen and water vapour to form chromium oxide. It is absolutely essential for perfect bright annealing to have an atmosphere quite free from traces of water vapour and free oxygen.

Wherever possible, it is advisable to carry out bright annealing treatments on austenitic steels in continuous furnaces, as more rapid cooling of the material can be effected than in batch installations.

Another class of steels which presents some difficulty is that containing high concentrations of silicon—i.e., steels used for transformer stampings—and whilst in batch installations a carbonaceous gas atmosphere may be used to purge out the container initially, the actual heat-treatment at temperature is nearly always carried out in a high hydrogen atmosphere, either purified cylinder gas or cracked ammonia.

(ii) *Bright Hardening and Tempering.*—The problems of bright hardening and bright tempering are confined exclusively to ferrous materials, and the atmospheres available for such treatments are similar to those previously cited for carbon steels. For plain carbon and low alloy steels, continuous furnaces provided with chutes dipping below quenching media are suitable, the method of conveying the material through the furnace being dependent upon the nature of such material—e.g., needles require some form of pan conveyer. In the case of bright hardening of plain and high-speed steels as tools, box-type furnaces are used—a controlled atmosphere derived from a carbonaceous source being preferable, and the articles transferred from the heating chamber to the quenching medium by hand.

Bright tempering furnaces are generally a modified form of standard tempering furnace, supplied with a fan for forced circulation and with a sealed lid, so that losses of protective atmosphere are reduced to a minimum. As tempering is generally carried out at temperatures below 650° C., the problem of decarburisation does not arise to the same extent as in bright hardening, and almost any form of dry protective atmosphere may be used with reasonably satisfactory results. In connection with the bright tempering, or more strictly the secondary hardening of high-speed steel tools, it has been found advantageous to use an atmosphere of cracked ammonia.

(iii) *Bright Brazing.*—Bright brazing is the process of joining together metallic articles in a controlled atmosphere with a suitable brazing medium, generally without the use of fluxes. Some of the first furnaces installed in this country were of the continuous type, and used copper as the brazing medium with controlled atmospheres derived from carbon-containing gases. In order to produce a satisfactory brazed joint when using copper at a temperature of 1,100° C., it is necessary to ensure cleanliness and a

close fit of the parts being joined. The better the fit, the better will the copper flow by capillary action. Another point which is sometimes lost sight of is that unless the articles being joined together in a particular atmosphere are capable of being bright annealed perfectly in the same atmosphere, then a poor brazed joint will result. Further, the minimum amount of copper consistent with making a good sound joint should be used. As a general rule, copper is used as a brazing medium when joining together ferrous materials, silver solders being used when brazing together non-ferrous materials and some special ferrous materials. When using silver solders, a slightly different technique is required, larger clearances between parts is required than with copper, and often a brush over with a fluxing medium is necessary.

It is usual to employ continuous furnaces for the bright brazing of small articles, the choice of atmosphere depending upon the materials being brazed. For mild steel parts burnt coal gas atmospheres are used, although brighter results are obtained by the use of burnt ammonia. For larger articles small batch furnaces of special design are employed. Fig. 6 shows an illustration of such a furnace used for the brazing of brass parts, using silver solders in an atmosphere of cracked ammonia.

It will be observed from the foregoing that the use of controlled atmospheres is now definitely established in metallurgical processes, and further research work is opening up new fields in which atmospheres play an important part.

The Heat-Treatment of Cast Iron by Hardening and Tempering

By J. E. Hurst

Cast-iron machinery components required to possess wear-resisting properties are submitted to a heat-treatment by hardening and tempering. This process is now practised extensively, and the treatment can be applied without risk of any deterioration in the mechanical properties of the material. Some investigations on the subject are discussed.

ONE of the many outstanding developments in the metallurgy of cast iron which have occurred during recent years is that of its heat-treatment by hardening and tempering. As a means of obtaining hardened cast-iron wearing parts for machinery, heat-treatment by hardening and tempering is now practised extensively, and it is now fully understood that such treatments can be applied without the risk of any deterioration in the mechanical properties. It is this knowledge, arising out of recent research and investigations, upon which the claim rests for hardening and tempering cast iron as a modern development in the field of the metallurgy of cast iron. Quotations from practical workshop handbooks, of which the following is typical, show that attention has been given for a long time to the hardening of cast iron by quenching :—

To Harden Cast Iron.—Heat the article to a bright red heat, and quench in a mixture of 3 gals. of water, ½ pt. of oil of vitriol, and 2 oz. of saltpetre. Another mixture for quenching consists of salt water, 10 gals. ; salt, 1 peck ; oil of vitriol, ½ pt. ; saltpetre, ½ lb. ; prussiate of potash, ½ lb. ; cyanide of potash, ½ lb. By repeating the process cast iron may be made harder. (Quotation from "Works' Managers' Handbook." Walter S. Hutton. 1901.)

The British Patent Records contain references to the hardening of cast iron, an early one dating back to the year 1839, recommended that cast iron be heated to a blood-red heat and quenched in water containing green vitriol or, alternatively, alum, saltpetre, and prussiate of potash. It is of some general interest to record that the majority of these early references apparently attach great importance to the quenching media, and a wide variety of different types of solutions embodying different salts, mixtures of salts and acids have been recommended. It is clear from modern research work that all these old processes would be successful perhaps in securing increased hardness, but in so far as none of these old mixtures appear to embody tempering treatments subsequent to hardening, it is to be presumed that the important effect of tempering in restoring the strength properties which are impaired by the quench hardening treatment, was unknown.

The Effect of Hardening and Tempering on Mechanical Strength Properties

This knowledge of the influence of suitable tempering treatments applied to cast iron in the quench-hardened condition in restoring and even improving the mechanical strength properties appears to be due entirely to modern research work, principally the writer's own investigations.[1] The results of these investigations show that when cast iron is subjected to hardening treatment by heating to temperatures above the A3 critical point, and quenched in a suitable media, either water or oil, an increase in hardness accompanied by a marked drop in ultimate breaking strength either in tension, compression, shear or transverse loading results. The magnitude of the increase in hardness varies, of course, with the chemical composition and the structural condition of the particular cast iron treated ; but the increment in hardness may be over 100 per cent. greater than the original "as cast" condition. In a like manner, the magnitude of the decrease in ultimate breaking strength varies according to particular conditions, but it can be of a very serious order, and reductions of over 50% in the ultimate strength value under conditions of transverse bending have been observed in quenched specimens. Tempering the quench-hardened specimens is accompanied by a recovery in the ultimate breaking strength value and all the investigations show that this recovery increases uniformly with increasing temperature until a maximum is reached followed by a decline with still further increment in tempering temperature. This phenomenon is accompanied by a decrease in Brinell hardness, and the general effect of quench hardening and tempering on the hardness value and strength properties is shown in Fig. 1.

Some idea of the magnitude of the influence of hardening and tempering on the hardness and ultimate breaking strength values is obtained from the graphs, Figs. 2 and 3. These embody the actual test results on a series of specimens of centrifugally cast chromium alloy cast irons containing varying amounts of phosphorus in accordance with the chemical analyses given in Table I. The quench-hardening effect has been obtained by quenching the specimens in oil from a temperature of 875° C., and it will be seen that, in this condition, an increment in hardness of from 244 to 534, nearly 100%, has been obtained in the low phosphorus specimen, and in the case of ultimate breaking strength in the same specimen, an increment of nearly 23% from 21·9 tons per sq. in. to 26·8 tons per sq. in. modulus of rupture stress.

This improvement in the strength properties of cast iron in the hardened and tempered condition is the outstanding

1 J. E. Hurst. Proceedings Institute of British Foundrymen. Vol. 24, p. 375, 1930-31 ; and vol. 25, p. 146, 1930-32. *Foundry Trade Journal*, vol. 45, p. 345. 1931.
Also Guillet, Gallisbourg and Ballay. *Comptes Rendues*, 1930, p. 538.
Also the investigations of F. B. Coyle, O. W. Potter, Piwowarsky, Durand, Grotts, Botschwar, Everest, Shore, Eddy and others.

discovery arising out of recent research work, and in that it has led to the establishment of confidence in the strength properties of hardened and tempered cast irons, it has been of immense importance in the commercial development of this method of hardening cast irons.

It has been shown[2] that the magnitude of the maximum improvement in strength results due to hardening and tempering is to an extent dependent upon the condition, whether sand cast or chill cast, and also upon the chemical composition, particularly as regards the total carbon and

TABLE I.

ANALYSES OF SPECIMENS OF VARYING PHOSPHORUS CONTENTS.

Spec. No.	Total Carbon. %	Comb'd Carbon. %	Graph., %	Si, %	Mn, %	P, %	Cr, %
1	3·39	0·52	2·87	2·21	1·07	1·56	0·52
2	3·49	0·49	3·00	2·16	1·08	1·30	0·71
3	3·44	0·30	3·14	2·44	1·01	1·06	0·59
4	3·55	0·46	3·09	2·35	1·00	0·63	0·61
5	3·58	0·39	3·19	2·44	0·93	0·58	0·62
6	3·60	0·54	3·06	2·44	1·09	0·43	0·55
7	3·81	0·59	3·22	2·49	1·02	0·035	0·61

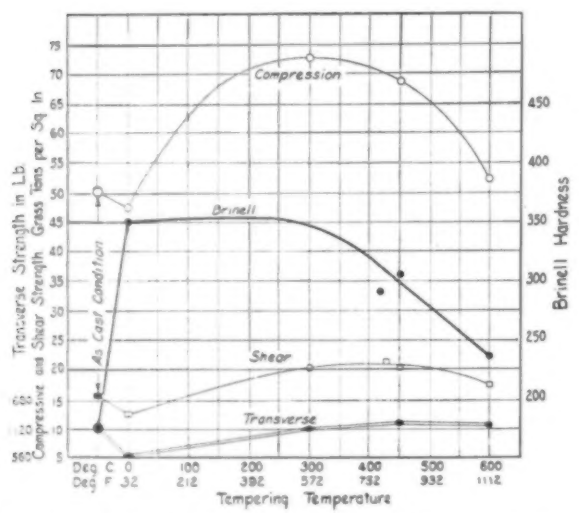

Compression
Brinell
Shear
Transverse
As Cast Condition
Transverse Strength in Lb Compressive and Shear Strength Gross Tons per Sq In
Brinell Hardness
Deg C 0 100 200 300 400 500 600
Deg F 32 212 392 572 732 932 1112
Tempering Temperature

Fig. 1.—Effect of hardening and tempering on strength properties (Guillet).

silicon contents. The effect of these conditions is demonstrated by the graphs, Figs. 4 and 5. The experimental work upon which these diagrams are based was carried out on a series of cast irons of the compositions set out in Table II. The specimens were quench-hardened in oil from a temperature of 850° C. and tempered in the usual manner.

The diagram, Fig. 4, is divided into three zones and shows the relation between the total carbon and silicon contents in sand-cast material, which yield improvements in strength properties of something less than 5% (Zone I), 5 to 10% (Zone II), and over 10% up to 20% (Zone III). The diagram, Fig. 5, is of particular interest in that, in addition

TABLE II.

CHEMICAL COMPOSITION OF SPECIMENS (PIWOWARSKY).

No.	Total Carbon. %	Graph., %	Comb'd Carbon, %	Total C. + Si, %	Mn, %	S, %	P, %
1	2·40	1·46	0·94	4·9	0·28	0·070	0·040
2	3·28	2·80	0·48	5·5	0·43	0·019	0·062
3	4·08	3·40	0·68	5·8	0·54	0·020	0·066
5	2·70	0·92	1·78	4·2	—	—	—
6	2·04	traces	2·04	3·9	—	—	—
4*	3·12	2·60	0·52	5·4	0·39	0·020	0·062

* Also contained 1·77% Nickel and 0·53% Chromium.

2 E. Piwowarsky, "Memoires du Congres Internationale," Brussels, No. 29, 1933.

to showing the limit of total carbon plus silicon contents in both sand-cast and chill-cast material beyond which very small improvement in strength properties is obtained, it shows also the greater magnitude of increment in the strength properties in the chill-cast material due to hardening and tempering. It is of importance to bear in mind that the test results given in connection with centrifugally cast material throughout this article are obtained on material cast in metal moulds, and as such are to be regarded as coming within the category of chill-cast material.

The Mechanism of Hardening and Tempering

The examination of quenched and tempered specimens under the microscope shows that exactly as in the case of steels the hardening effect is due to the formation of martensite, and the effect of tempering at successively higher temperatures is accompanied by a gradual change from the martensite to sorbitic structures. It is of some theoretical and general interest to note that the series of specimens detailed in Table I responded to hardening and tempering after a preliminary drastic annealing treatment at 900° C., although some irregularity in the extent of the hardening was noted, particularly in the high phosphorus content specimens.

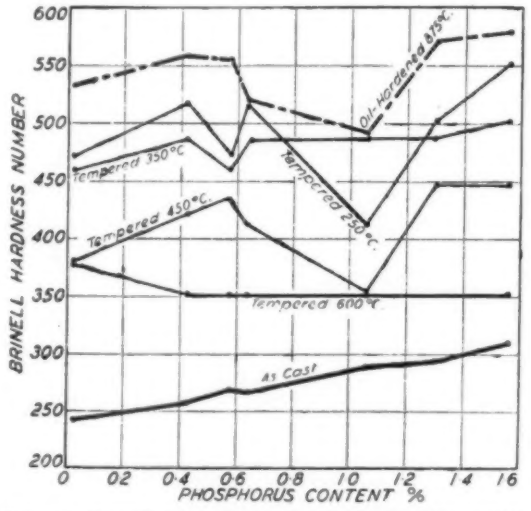


Fig. 2.—Brinell hardness of hardened and tempered specimens of varying phosphorus contents.

TABLE III.

CHEMICAL ANALYSES OF CENTRIFUGALLY CAST SPECIMENS OF VARYING PHOSPHORUS CONTENTS AND FINE GRAPHITE STRUCTURES.

Sample No.	Total Carbon, %	Graph., %	Comb'd Carbon, 4%	Si, %	Mn, %	P, %
1	3·49	3·49	Nil	2·49	0·55	0·022
2	3·47	3·28	0·19	2·49	0·59	0·526
3	3·52	3·03	0·49	2·63	0·41	0·56
4	3·49	2·79	0·70	2·58	0·63	0·66

An additional example is of interest, and is taken from the series of specimens, the chemical compositions of which are set out in Table III. This again is a series of centrifugally cast specimens of varying phosphorus contents, and in the low phosphorus specimen No. 1 the chemical analysis shows the combined carbon as being completely absent. The hardness results in Table IV show clearly that this specimen has hardened to even a greater degree than the specimens containing an initially higher combined carbon content. As a matter of fact, in this specimen, although the chemical analysis showed combined carbon to be completely absent, the microstructure showed the presence of very slight traces of pearlite. In order to make certain that hardening could take place in the complete absence of pearlite, specimens from the same castings were drastically

TABLE IV.

MECHANICAL PROPERTIES OF SPECIMENS AS DETAILED IN TABLE III.

	Specimen No.	As Cast.	OQ 875° C. Temp. 275° C.	OQ 875° C. Temp. 450° C.
Modulus of Rupture, tons per sq. in.	1	22·8	48·2	44·5
	2	27·2	42·5	43·5
	3	28·0	41·25	43·3
	4	23·2	37·3	36·2
Modulus of Elasticity lb. per sq. in. × 10^6	1	16·1	15·5	14·1
	2	16·6	14·4	15·3
	3	17·5	16·9	16·1
	4	15·7	15·5	15·6
Permanent Set, %	1	9·95	3·56	5·0
	2	21·7	7·7	5·0
	3	15·1	6·25	5·35
	4	22·2	5·85	4·7
Brinell Hardness	1	163	474	412
	2	196	488	390
	3	207	412	380
	4	196	435	423

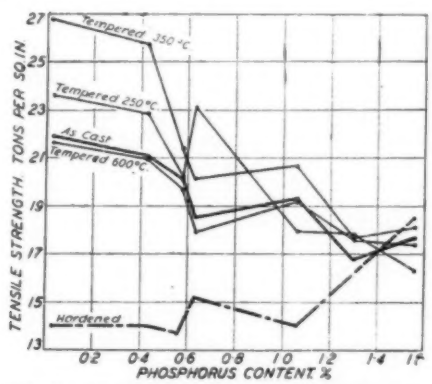


Fig. 3.—Tensile strength of hardened and tempered specimens of varying phosphorus contents.

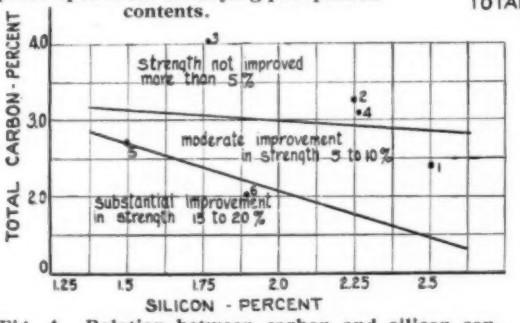

TOTAL CARBON - PERCENT
SILICON - PERCENT
Strength not improved more than 5%
moderate improvement in strength 5 to 10%
Substantial improvement in strength 15 to 20%

Fig. 4.—Relation between carbon and silicon contents and improvement in strength results due to hardening and tempering (Piwowarsky).

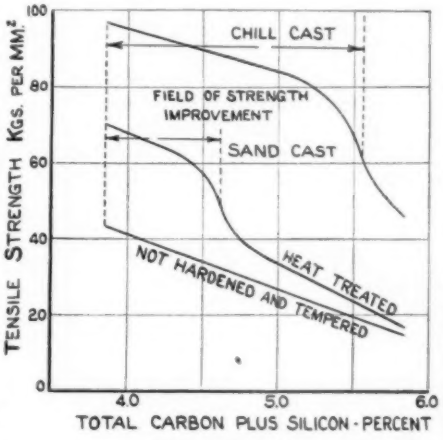


Fig. 5.—Diagram showing relation between total carbon plus silicon—condition and field of strength improvement.

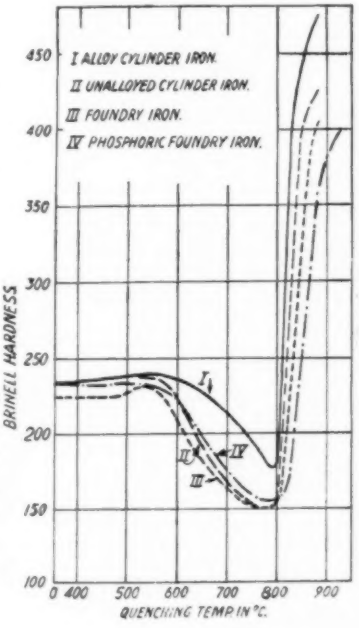


Fig. 6. — Hardness after quenching from various temperatures. (Schwartz and Vath).

annealed at 950° C. for a total period of 16 hours' heating and cooling, and even with the complete absence of initial pearlite, the specimens were found to respond to the hardening and tempering treatment. The results of this particular investigation, in Tables III and IV, have been included with the object of drawing attention to the important effect of the condition of the graphite on the test results obtained. These specimens possessed structures of the ferrite-fine graphite type, in a well-developed form in the low phosphorus specimens, diminishing somewhat in form and magnitude in the specimens with increasing phosphorus. It is impossible to resist the conclusion that these exceptional improvements in mechanical strength properties are associated with this structural condition of the graphite. Further investigations appear to confirm this view.

The part played by the graphite not only in the magnitude of the improvement in mechanical strength properties, but also in the actual mechanism of hardness as revealed by these results, is of special importance, and introduces considerations and phenomena different from those experienced in the hardening and tempering of steels. In an investigation of the hardness of four irons whose compositions are shown in Table V, after-quenching from different temperatures, Schwartz and Vath[3] obtained the results as shown in the diagram, Fig. 6.

Quenching from temperatures within the range of approximately 550° C. to 790° C. in each case is accompanied by a drop in hardness from that of the original "as-cast" condition. From temperatures in excess of from 775° C. to 790° C., quenching is accompanied by the hardening effect, and apparently in these specimens, and under the conditions of the experiment, the maximum hardening effect is obtained with quenching temperatures in the neighbourhood of 900° C. It is known that heating cast irons within the temperature range of 550° C. to 790° C., the combined carbon undergoes decomposition, and it is suggested that the softening effect on quenching from these temperatures, as revealed by the results, is due to this cause, a fact which suggests that under many conditions the decomposition of the combined carbon, pearlite, initially present in the cast iron may be a preliminary to hardening by quenching from temperatures high enough to secure the re-solution of the graphite thus formed.

3 Schwartz and Vath. *Giesserei*, vol. 21, p. 345. 1934.

TABLE V.

COMPOSITION OF CAST IRONS, SCHWARTZ AND VATH EXPERIMENTS.

Type of Iron.	Total Carbon, %	Si, %	Mn, %	S, %	Ph, %	Ni, %	Cr, %
1. Alloyed cylinder iron	3·15	1·90	0·62	0·018	0·46	1·04	0·35
2. Non alloy cylinder iron	3·02	2·03	0·62	0·032	0·55	—	—
3. Foundry iron	2·99	1·92	0·62	0·030	0·73	—	—
4. Phosphoric foundry iron	3·20	2·45	0·70	0·105	1·37	—	—

Considerations of this nature have an important bearing upon the question of the most effective quenching temperature. In some careful experiments conducted by the author in an investigation of the effect of quenching temperatures, effective hardening was obtained by quenching in oil from 800° C., the hardness value attained being constant over a range of quenching temperatures of from 800° C. to 860° C., and actually falling slightly at a quenching temperature of 920° C. The strength results obtained in these experiments after quenching and tempering at various temperatures are illustrated in the diagram, Fig. 7.

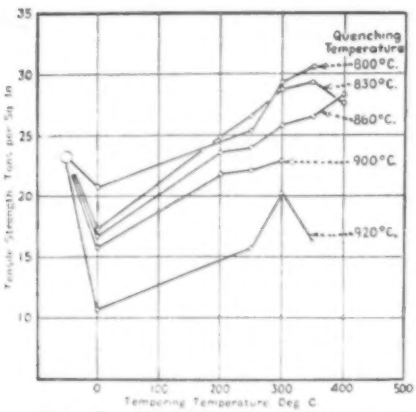


Fig. 7.—Showing the influence of quenching temperature on tensile strength after tempering.

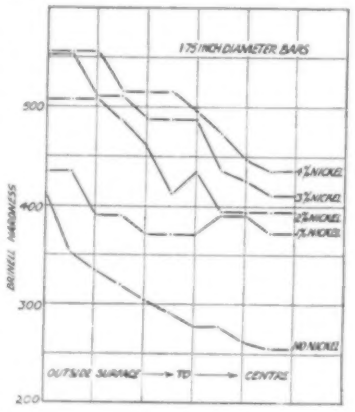


Fig. 8.—Effect of varying nickel contents on depth of hardening on 1.75-in. diameter bars.

and show clearly the influence of nickel in improving the depth of penetration of the hardening effect. In this case, 2·0% of nickel ensures a hardness value of at least 375 in the centre of the 4-in. diameter bar.

It is not the place to detail the results which have been obtained from various alloy cast-iron compositions, as many results on plain nickel manganese, nickel chromium, molybdenum and alloy compositions containing vanadium, aluminium, titanium, and other alloy additions have been published.

It is impossible to pass from these considerations without making reference to the important results obtained from the joint additions of molybdenum and manganese. With combinations of manganese and molybdenum strength values of a very high order are obtained after suitable

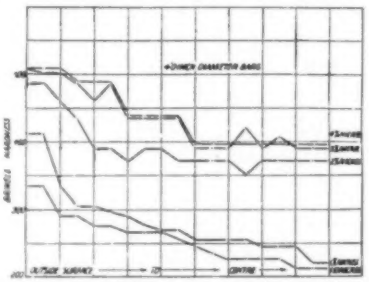


Fig. 9.—Effect of varying nickel content on depth of hardening in 4-in. diameter bars.

The Influence of Chemical Composition and Alloy Additions

From experiments conducted on centrifugally cast material it has been shown that in suitable thin sections plain unalloyed cast irons are susceptible to the hardening and tempering treatment. Of the elements present normally in cast iron, phosphorus has been systematically studied. The results referred to in the first section of this article have been taken largely from this study, and whilst the investigations were made with a cast iron containing chromium, it is probable that they can be regarded as indicating the characteristic influence of phosphorus.

TABLE VI.

CHEMICAL ANALYSES OF SPECIMENS OF VARYING NICKEL CONTENTS.

Spec. No.	Total Carb., %	Com. Carb., %	Gra., %	Si, %	Mn, %	P, %	Ni, %	Cr, %
1	3·71	0·57	3·14	1·92	0·96	0·45	Nil	0·11
2	3·76	0·41	3·35	1·97	1·02	0·48	1·18	0·11
3	3·71	0·43	3·28	1·92	0·96	0·47	2·05	0·11
4	3·71	0·36	3·35	1·92	0·99	0·49	2·97	0·15
5	3·71	0·43	3·28	1·97	0·94	0·47	4·10	0·15

As would be expected, the influence of alloy additions is accompanied by marked improvements in the results obtained, and as in the case of steels, the outstanding alloying elements are nickel, manganese, chromium, and molybdenum. The influence of these elements exerted through their influence on the position of the critical points A3 and the critical speed of quenching is utilised to provide effects similar to those which accompany their use in steels. In the case of nickel, its important influence on the depth of penetration of the hardening effect is shown clearly by the following experimental results obtained on chill-cast bar specimens of the analyses as recorded in Table VI. Prior to hardening, all the bars were submitted to a uniform annealing treatment at a temperature of 900° C., and after this treatment the Brinell hardness results on the outside surfaces of the bars were as shown in Table VII. Cross sections of the varying diameter bars cast as indicated in Table VII were hardened by quenching in oil from a temperature of 875° C., and the Brinell hardness values across the section, from the edge to the centre, determined. These results are given in the diagrams, Figs. 8 and 10,

hardening and tempering treatments. Reference might be made here to some experimental work on the influence of molybdenum additions on the properties of an aluminium chromium nickel cast iron, after exposure to treatment at a temperature of 500° C. Some of these results were carried out on an aluminium chromium alloy cast iron suitable for nitrogen hardening, and it was observed that when nickel was present particularly there seemed to occur a marked falling off in strength properties after exposure to the nitrogen hardening treatment at a temperature of 500° C. for a period of 90 hours. These results appeared to bear some resemblance to the phenomena of temper brittleness

TABLE VII.

BRINELL HARDNESS VALUES OF SPECIMENS IN TABLE VII IN ANNEALED CONDITION.

Diameter of Bar, In.	Nickel Contents. (1) Nil %	(2) 1·18 %	(3) 2·05 %	(4) 2·97 %	(5) 4·10 %
1·75	212	217	228	207	228
4·0	207	196	207	212	228
5·5	179	187	196	187	217

in steels which at once suggested the possibility of exploring the influence of molybdenum.

The effect of certain alloy additions in increasing the critical quenching speed can be taken advantage of in the production of alloy cast irons suitable for air-hardening treatments. A typical example is the nickel chromium alloy to the following specification :—

	%	Preferred Composition. %
Total carbon	2·70 to 3·50	3·00
Silicon	1·00 „ 3·00	1·80
Manganese	0·5 „ 1·5	1·00
Sulphur	0·14 maximum	0·06
Nickel	3·00 to 6·00	4·50
Chromium	1·50 „ 2·00	1·75

This can be hardened by heating to 800° to 850° C. and allowing it to cool in air, and can be softened by a tempering treatment at 680° C. The effect or air-hardening and tempering treatments on the mechanised strength properties follow the same lines as the quench-hardening and tempering treatments previously described.

Some Recent Heat-treatment Furnace Installations

Recent years have seen intensive development in both the design and application of heat-treatment furnaces. Progress in the use of special alloys in both ferrous and non-ferrous fields has necessitated more critical time and temperature limits, while improvements in furnace equipment have been further accelerated by mechanical handling of the products treated and by atmosphere control. In this article brief reference is made to the features associated with some recent installations.

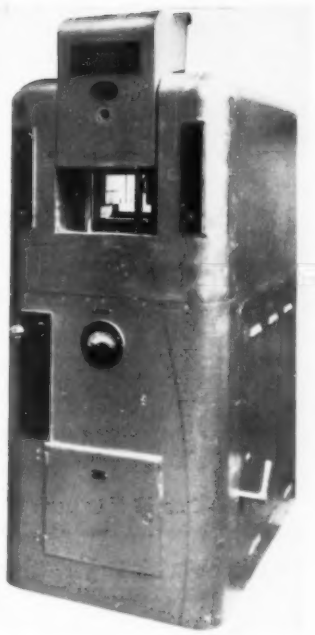


Fig. 1.
An electric hardening furnace with atmosphere control.

THE primary object of most heat-treatment operations is the attainment of the final structure having the desired physical properties. Additional refinements may also be desirable, such as a bright or clean finish on the material treated, in which scaling, decarburisation, and other chemical reactions are eliminated from the heat-treatment process. Refinements of this character may have useful economic advantages, since they eliminate secondary cleaning operations which may be as costly as the heat-treatment process. But satisfactory results in the achievement of the primary object is dependent upon the equipment, the material or component, and the person responsible for carrying out the heat-treatment operation.

Assuming that the material meets the appropriate specification and the heat-treater is an experienced man, the most suitable type of furnace for a given operation depends upon many factors, but the value of the result desired is of primary importance in determining the type. The cost of the heating medium employed, temperature and atmosphere control, and other phases in heating operations are really incidental to the main consideration, which involves the quality of the finished product and its overall cost. In other words, when making a choice it is important to bear in mind the need for producing a high-grade product at low cost, using that form of heating medium and that type of equipment which will give these results under the particular conditions that operate in the works at which the installation is contemplated. The choice is frequently a compromise between that which is considered to be best in theory and one which, when viewed with the conditions of the particular case, is practical.

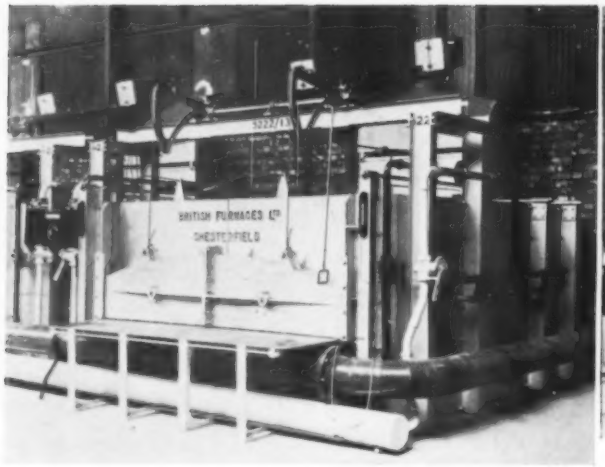
The first function of a furnace is to give a satisfactory product, as to degree of uniformity of heating, consistent with possible variations of output and conditions imposed by the shop requirements. In this respect, since the products are being heated for treatment in their final stages of manufacture, there is a standard of accuracy of temperature and uniformity, a degree of reliability and ease of control, that may not be attainable except with the most refined and elaborate methods. The actual cost of heat units utilised in the furnace is a matter secondary to the essential needs of attaining the required standard of quality of product, since cost of failure far outweighs the small increment of cost in the actual energy applied, and the capital charges involved in more complicated plant.

In assessing the relative importance of the many factors involved, local conditions play a part, but the guiding principles are concerned mainly with reliability and flexibility of output and ease of control. With the tendency towards mass production in many industries, the duty demanded of heat-treatment furnace units may amount to a very precise and clearly defined treatment and output. The allowable margin to cover contingencies and unknown factors is much reduced in modern furnaces of a specialist character, but a fair measure of flexibility of output and range of temperature is demanded in many types of general heat-treatment plant. With respect to ease of control, there must usually be a compromise between an installation so far mechanically controlled that it may be regarded as "fool-proof" in operation and a complicated mechanism which requires special handling. Modern furnaces are readily made automatic as regards temperature control, and for many materials the use of atmosphere control is making great progress. The question of refractories cannot profitably be omitted from consideration. Special attention must be given to this factor, since provision may be necessary to resist erosion sometimes encountered.

Whatever the medium employed to supply the necessary heat to the furnace chamber, it should be remembered

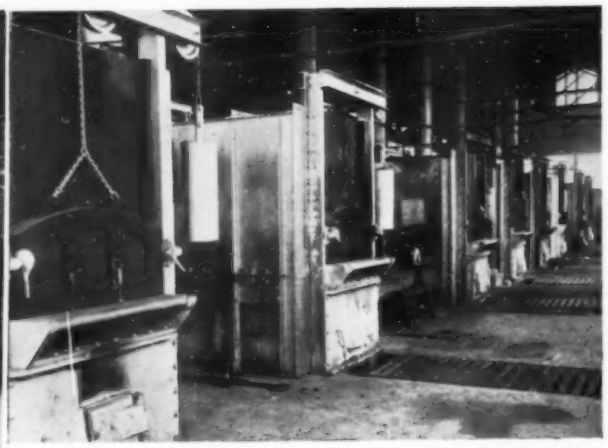
Courtesy of Stein and Atkinson, Ltd.

Fig. 2.
Large bogie annealing furnace for forgings fired by producer gas.



Courtesy of British Furnaces, Ltd.

Fig. 3.—One of a battery of 22 town's-gas-fired brass annealing furnaces.



Courtesy of Augusts, Ltd.

Fig. 5.—A battery of coke-fired muffle furnaces for the heat-treatment of steel bars.

that the object is to heat the charge so that it possesses a uniform temperature determined by the material of the charge and the particular form of treatment desired. The furnace chamber, therefore, should be designed to facilitate the transfer of heat to the charge, and uniformity in temperature of the charge is dependent upon the method of heat transfer. Heat is transferred by conduction, convection, and radiation. When a charge is heated by conduction it is in direct contact with a hotter material. The hotter material may be the hot hearth of a furnace chamber, a salt bath, or the hot gas of the furnace atmosphere. In salt baths convection is combined with conduction, since the cold charge causes movement of the salt bath until the charge and salt bath are the same temperature. When the salt bath is internally heated electrically the movement of the salt bath is continuous and produces natural convection. Forced convection is obtained by stirring the bath, or the atmosphere surrounding the charge may be kept in constant movement by means of a fan or by the suitable arrangement of burners and flues in fuel-fired furnaces. One of the most important developments in the design of heat-treatment furnaces in recent years is concerned with the circulation of heat.

Types of Furnaces

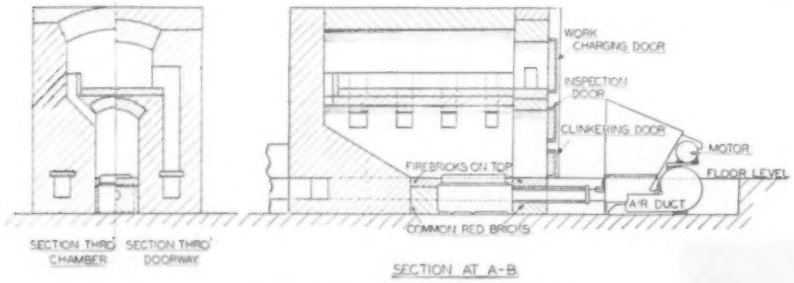
In general, most heat-treatment processes may be divided into batch and continuous methods. The batch method, with the simple box-type chamber, was developed first, and will always be popular owing to its adaptability to products varying widely in size, quantity, and even type of treatment. When the output of a product requiring the same heat-treatment is fairly constant, an opportunity is provided for using some type of furnace in which the material to be treated is automatically handled, involving a continuous furnace. In addition to temperature control, and in many cases atmosphere control, these furnaces also have time-cycle control and are designed to repeat accurately a required treatment with a view to obtaining uniform products. Some examples of these types of furnaces will show the wide variations in design to meet industrial requirements.

The difference in size of batch furnaces used is indicated by Figs. 1 and 2. The former, an electric hardening furnace with atmosphere control, is so designed that all the door-operating gear, switchgear, transformer, and atmosphere control equipment are totally enclosed under the furnace chamber, so that the equipment is neat and compact and can be kept clean and tidy with little effort. The elements in the furnace, 80/20 nickel-chromium, are supported in special refractories in the roof, side-walls and hearth. A wall-mounted automatic temperature controller is included as part of the equipment.

The furnace shown in Fig. 2 is designed and installed for annealing heavy steel forgings; it has a hearth area of 60 ft. long by 9 ft. wide, and is used for annealing charges weighing up to 80 tons, comprising shafts, some of which are 50 ft. long, and forgings of a diameter up to 8 ft. It is fired with raw producer gas, and is equipped with burners designed to ensure correct mixing of gas and air and to proportion these so that combustion is controlled in a scientific manner. Combustion is generated above the charge, and the circulation of the neutral products of production is such that the charge is enveloped by these gases. Records from long thermocouples placed against

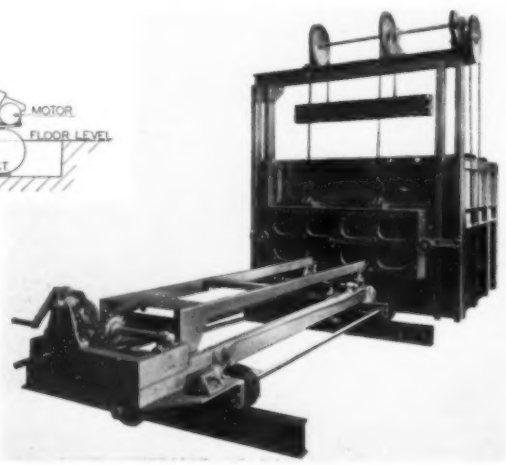
Fig. 4.—An electric annealing furnace with patent hand-operated charging mechanism.

Courtesy of Metalectric Furnaces, Ltd.



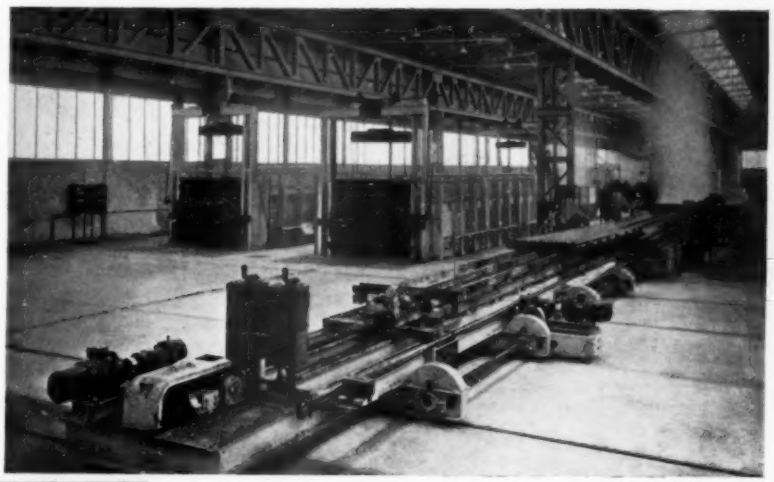
Courtesy of Mirrlees, Bickerton and Day, Ltd.

Fig. 6.—A carburising furnace heated by means of a mechanical stoker showing the arrangement of the furnace in relation to the stoker.



different points of the charge show the greatest uniformity of heat distribution, also scaling of the charge is minimised, due to the neutral character of the gases enveloping it. Recuperators are used for preheating the air for combustion, and are sub-divided and disposed at the side of the furnace, making it possible to carry the bogie on solid concrete work. The pressure burners are divided into groups so that the gas may be divided for control purposes.

The furnace shown in Fig. 3 is one of 22 furnaces installed in a Government factory for the annealing of brass. Each has an effective hearth width of 8 ft. × 9 ft. 6 in. long, and is used for heating 70/30 brass to a temperature of 635° C. for annealing. Heating is accomplished by 12 tunnel burners in each furnace, and these are supplied with a correctly proportioned gas-air mixture by means of two low-pressure inspirators, one on each set. These inspirators are supplied with air at a pressure of 1 lb. per sq. in. along with town's gas at ordinary mains pressure. They automatically maintain a correctly proportioned gas-air mixture, resulting in perfect combustion and a uniform furnace atmosphere.



Courtesy of Stein and Atkinson, Ltd.

Fig. 7.—A plant for annealing non-ferrous metals.

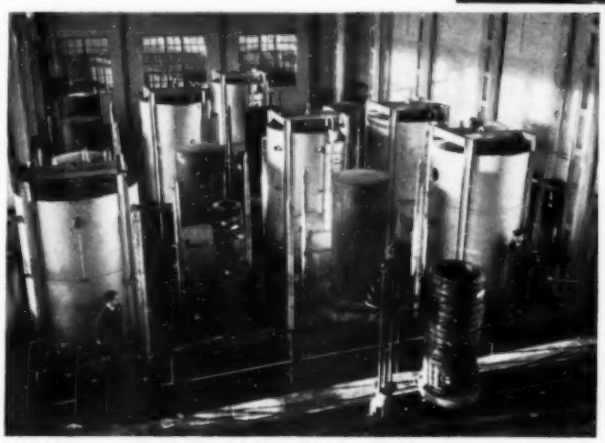


Fig. 8.—A battery of "Birlec" bell-type furnaces for bright annealing steel strip in coils.

The gas-burner nozzles are inclined upwards to fire just under the arch, the products of combustion being taken away through outlet ports at hearth level, so that the charge is completely immersed in hot gases. After leaving the furnace chamber, the gases pass backwards and forwards under the hearth, and their sensible heat is utilised to counteract the thermal losses which normally occur at this point. They then flow through controllable uptake ports built in the back wall of the furnace, and are finally exhausted to atmosphere at low temperature.

The electrically heated furnace in Fig. 4 is designed for general use as an annealing or carburising furnace. It is economical for temperatures up to 1,000° C., when full use can be made of the heating chamber, which is 6 ft. 6 in. long and 1 ft. 6 in. high. In the foreground is the patent hand-operated charging mechanism associated with this furnace. The special features claimed for this furnace, in addition to precision control of temperature, are high thermal efficiency due to thorough insulation, and simplicity of operation. A batch furnace of the muffle type is illustrated in Fig. 5, which shows a battery of eight of these furnaces for operating up to 1,000° C. The muffle dimensions of each furnace are 18 ft. long, 3 ft. 2 in. wide, and 1 ft. 6 in. to the crown of the arch. These furnaces are coke-fired from either or both ends, and are complete with bar handling and quenching gear. Heavier bars are charged and discharged by means of a special bar-charging device, but light bars are handled manually. An interesting feature is the speed of transferring the heated bars to the quenching tank. The quenching tanks, both oil and water, are connected to automatic coolers, so that the temperature in the quenching tanks is known and constant.

Very few heat-treatment furnaces, as distinct from heating furnaces, burn coal, but an economical and satisfactory way of using coal has been developed in which coal is fed to a fire below the chamber being heated. In this process of gradual heating, volatile and smoke-forming gases are liberated and burnt completely by the incandescent part of the fire. The method is indicated in Fig. 6, and comprises a mechanical stoker from which a worm-conveyer feeds the fire with a relatively cheap grade of coal. The arrangement shown in the illustration is designed for carburising treatment. Air is supplied by a fan, and can easily be regulated to facilitate combustion or to control the condition of the atmosphere in the heated chamber.

A plant for annealing non-ferrous metals is shown in Fig. 7. It comprises one town's gas-fired closed-muffle

Fig. 9.—A battery of Grunewald furnaces for bright annealing mild steel strip in coils.

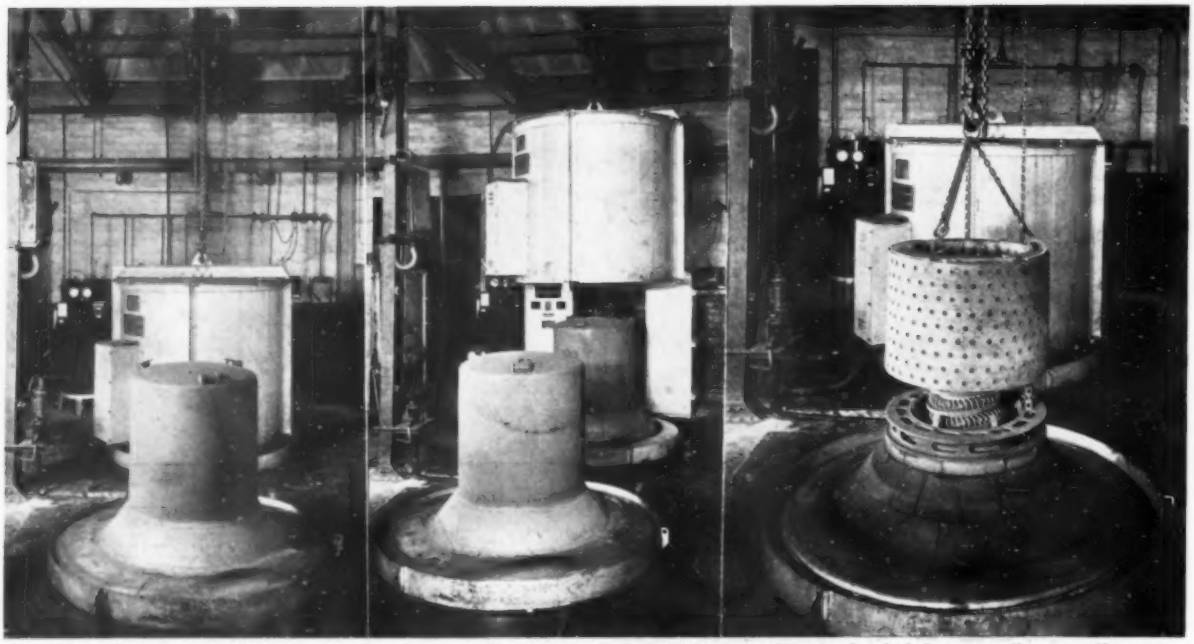


Fig. 10.—Three views of a bell-type furnace installed at the G.E.C. Telephone Works for bright annealing small parts.

furnace, with hearth 6 ft. by 22 ft., capable of operating at temperatures between 450° and 850° C.; one town's gas-fired open-annealing furnace, with hearth 6 ft. by 32 ft., capable of operating at temperatures between 500° and 950° C.; and one four-arm charging machine, charging table, and bosh for quenching. Air for combustion is pre-heated in recuperators of the natural-draught type. The burners, operating at town's gas pressure, consist of heat-resisting nozzles extending across the hot air flues, and as they are positioned on either side of the furnace the products pass in alternate directions, maintaining to fine limits uniform temperature throughout the whole furnace chamber. The burner design, having the feature of correct mixing and proportioning of air and gas, allows precision control of combustion. Automatic temperature control equipment is included, which, operating the main gas valve and air valve, enables the furnace temperature to be controlled with the minimum amount of attention.

The four-arm charging machine, electrically operated, enables the charge to be entered into the furnace and lowered on to the hearth. On discharging, the charge is lifted and withdrawn and may be lowered on to the charging table for quenching. The quenching charging table is operated with a closed circuit oil hydraulic system, and is arranged so that one end of the table may rise before the other to facilitate quick draining of the annealed tubes, etc.

Uniformity of heating and cooling presents many problems in the case of sheets, coiled strip or wire. A single sheet can be treated more easily than stacked sheets, and, as a rule, specially designed furnaces are necessary. The lift-off bell-type furnace is a type suitable, and Fig. 8 shows a battery of " Birlec " furnaces of this type for bright annealing coils of steel strip, wire, etc. Each furnace is rated at approximately 110 kw., and has four hearths to take coils up to 3 ft. diameter. Each hearth is fitted with a gas-tight cover and atmosphere circulating fan to ensure uniform annealing. The special atmosphere established under the cover is such as to permit high carbon steel to be annealed without either scaling or decarburisation.

Another battery of furnaces for bright annealing mild steel strip in coils is shown in Fig. 9. These are Grunewald furnaces, and two are rated at 120 kw. each, the pots having effective loading spaces of 36 in. diameter by 48 in. deep; the other two furnaces are rated at 130 kw. each and are 44 in. diameter by 48 in. deep. A G.E.C. town's gas burner, which produces the atmosphere, can be seen on the left-hand side of the illustration. These furnaces are installed at the works of Messrs. The Whitehead Iron and Steel Co., Ltd., Newport, Mon., who, incidentally, have six more furnaces of this type.

Three views of a bell type furnace, installed at the G.E.C. Telephone Works for the bright annealing of small parts, are shown in Fig. 10. In this case cracked ammonia is used to provide the furnace atmosphere. The illustrations show the sequence of operations, that on the left showing, in the foreground, a charge with the cover over it, resting on a special base, and, in the background, the furnace in position on a second base. In the centre illustration the furnace is raised, while the method of charging is shown in the illustration on the right. This furnace is rated at 40 kw.

Fig. 11.—A battery of box-type electric furnaces for annealing brass and copper strip in coils.

Courtesy of G.W.B. Electric Furnaces, Ltd.

A battery of four box-type furnaces for annealing brass and copper strip in coils is shown in Fig. 11. An electric machine is used for charging and discharging. The chamber dimensions of each of these furnaces are 18 ft. long by

Fig. 12.—Single and double row Surface Combustion Corporation design of radiant tube annealing covers for annealing coils of tinplate.

Courtesy of Stein and Atkinson, Ltd.

4 ft. wide by 1 ft. 10in. high. Strip elements are fitted in roof, hearth, and side-walls, the rating being 180 kw. Forced air circulation is provided by means of four patent centrifugal fans located in the roof.

A more recent development is a device in which gas is burned inside a heat-resistant alloy tube, the walls of which radiate heat in the furnace chamber, while the products of combustion pass on through the tube and do not enter the furnace chamber. This method lends itself to the use of radiant tube covers similar to those shown in Fig. 12. These illustrate the Surface Combustion Corporation design of radiant tube covers for annealing steel sheets and tinplate, the essential feature of which is the application of heat to the charge from horizontally disposed tubes. The lower tubes are of greater heating capacity than the upper tubes, and the heating of the lower part of the charge and the base is, therefore, carried out at the same rate as the upper part of the charge. In practice it is found that temperature records on a continuous strip chart, taken from various parts of the charge, merge into a single line.

The rate of heating and soaking is controlled by an automatic on-and-off control acting on all tubes. Suitable by-pass and pilot burners allow for safe operation under all conditions. The design of burner giving low velocity stream-line flow of the incoming air and gas results in a central core of luminous flame, which develops by diffused combustion into fully combusted gases and ensures even temperature along the whole length of tube. Full use is made of the fuel gas by the long tube, resulting in minimum fuel consumptions.

The horizontal disposition of the radiant tubes allows the covers to be offered in two designs—i.e., the single-row cover, which has tubes disposed on each side and the double-row cover, which has additionally a further row of tubes disposed horizontally down the centre of the cover. The double-row cover has been developed for annealing coils and also for sheets up to 50 in. wide, whereby packs of sheets or stands of coils may be stacked between each row of tubes and thus obtain the most efficient heat transfer from the radiant tube simultaneously on both sides of each pack, therefore increasing the heating capacity of the cover by close on 100%.

Fig. 12 shows a section of an annealing plant for tinplate coils : this installation includes both the single and double row covers. Three stands of coils are contained in the former and eight in the latter. Each coil stand is equipped with a special high-temperature fan, situated in the base. Each stack of coils is covered with a light, specially treated steel cover. The special inert gas inside the inner cover is circulated by the fan, thereby increasing the natural convection currents and producing not only even heat-treatment, but also a high rate of heat transfer, and thus a high output per unit. It is noteworthy that, although this type of furnace is relatively new, over 200 installations of this type of cover have been carried out.

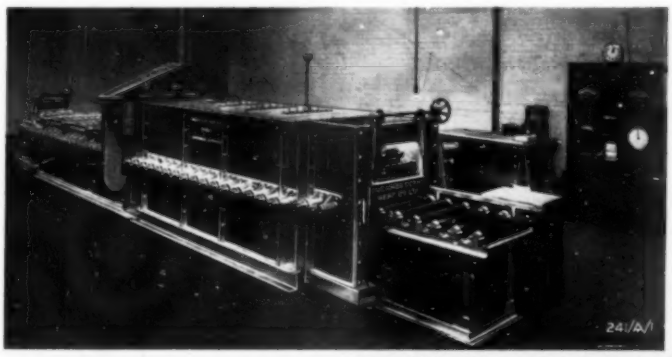
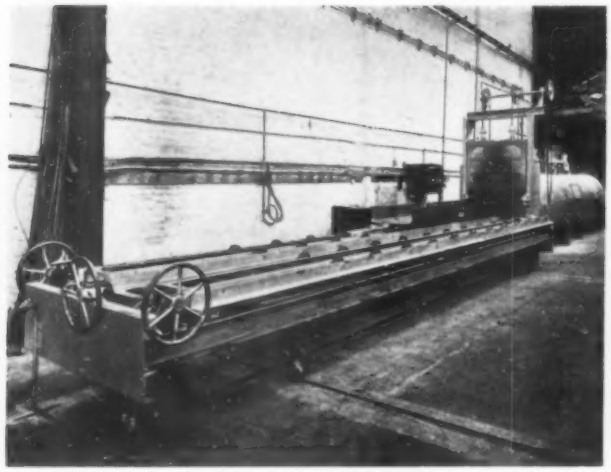


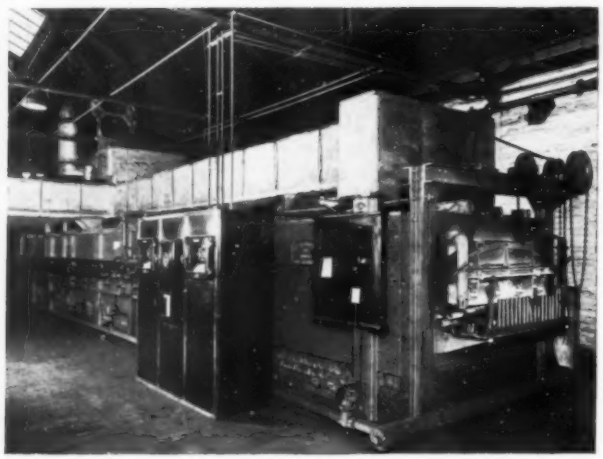
Fig. 13.—A multi-radiant town's-gas-fired continous conveyer-type furnace by Incandescent Heat Co., Ltd.

Fig. 14.—A battery of eight vertical pit-type "Birlec" furnaces for the heat-treatment of gun tubes.



Courtesy of Metalectric Furnaces, Ltd.

Fig. 15.—An electrically heated horizontal cylindrical furnace for the heat-treatment of aluminium alloys.



Courtesy of British Furnaces, Ltd.

Fig. 16.—A town's-gas-fired wire patenting furnace of the open type.

Another design of radiant tube furnace is the patent incandescent multi-radiant town's-gas-fired continuous conveyer-type furnace shown in Fig. 13. This system has been successfully applied to a wide range of heat-treatment operations, covering ferrous and non-ferrous metals in the form of pressings, strip, wire, sheets, tubes, etc., from the low-temperature treatment of brass and light alloys to the bright treatment of stainless steel, copper brazing, etc., at temperatures up to 1,100° C. The system has also been applied successfully for continuous automatic bright hardening.

A battery of eight vertical pit type "Birlec" furnaces for the heat-treatment of gun tubes at a Government factory is shown in Fig. 14. Each furnace is approximately 25 ft. deep by 3 ft. diameter, with a rating of 450 kw., the elements being divided into a number of separate zones for ensuring utmost uniformity of temperature distribution. The complete installation is the largest of its kind in the country, and has exceptionally complete control equipment, enabling any time-temperature cycle to be followed separately in each furnace with complete, continuous records of each treatment. The furnaces are used for tempering, hardening, etc., at temperatures up to 1,000° C.

Fig. 15 shows an electrically heated horizontal cylindrical furnace for the heat-treatment of aluminium alloys. The furnace is of the Multi-Zone type, and has chamber dimensions 25 ft. by 2 ft. 6 in. diameter. This unit is designed for low-temperature annealing of non-ferrous sections at 400° C., and has a connected load of 120 kw. The output is 10 cwt. per hour. Accurate and even temperature control throughout the furnace is assured by the special disposal of heating elements and design of fans used. Materials under treatment are heated by air convection only, by which it is claimed over-heating or unequal heating is avoided.

Many furnaces are specially designed to remove the strains set up in the cold-drawing of steel wire and to determine the final grain structure. It is necessary that these patenting furnaces should be capable of close adjustment, both as regards temperature and atmosphere. Fig. 16 shows a town's-gas-fired wire-patenting furnace of the open type, having a hearth 4 ft. wide and 50 ft. long. It is heated with 40 burners, 20 on each side, firing just above the hearth, and these burners are located for about two-thirds the length of the furnace. Each burner is combined with an automatic proportioning inspirator which exactly and automatically controls the air-gas mixture supplied to the burner. The ratio of the air and gas in the mixture determines the furnace atmosphere, which can be oxidising, reducing, or neutral. In the case of patenting furnaces, a neutral atmosphere is vital, as it reduces scaling to an absolute minimum, thereby reducing the loss of material and cost of working.

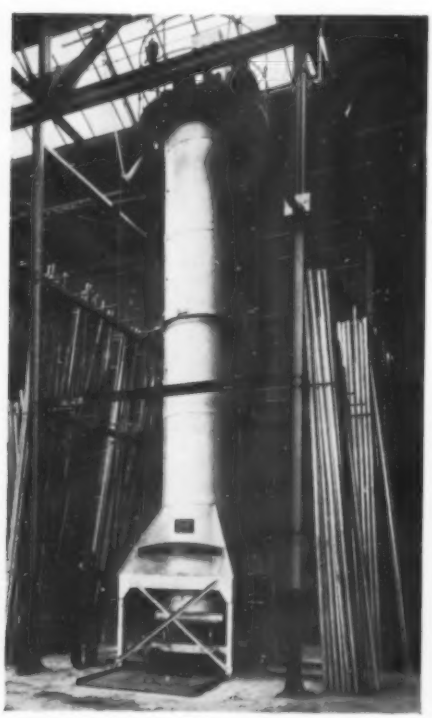
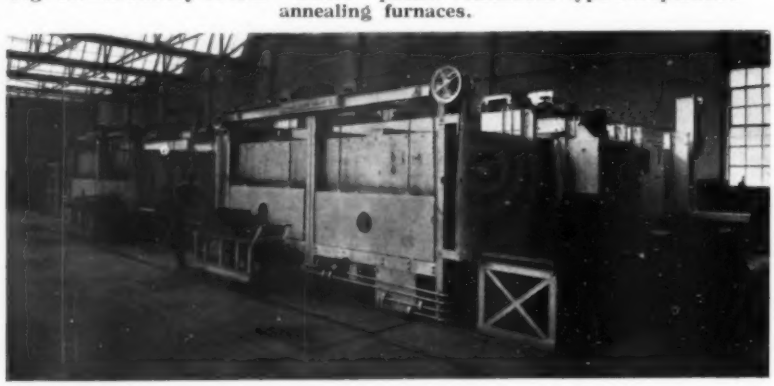
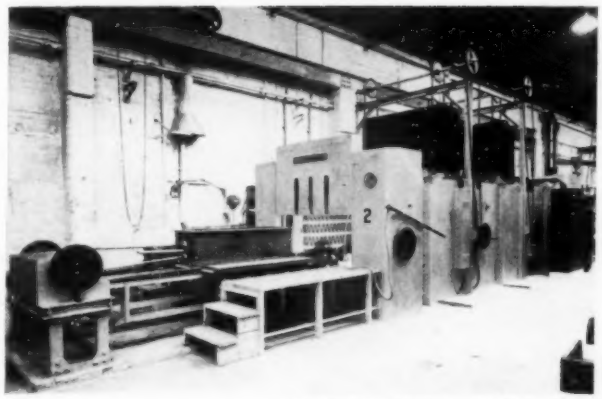


Fig. 17.—A vertical forced-air circulation furnace for the solution heat-treatment of light alloy aircraft sections.

Courtesy of Electric Resistance Furnace Co., Ltd.

Fig. 18.—A battery of four "Birlec" pusher continuous-type recuperative annealing furnaces.





Courtesy of G.W.B. Electric Furnaces, Ltd.

Fig. 19.—A double-ended nitriding furnace which can be used as one, two or three separate units.

Up to 32 strands are drawn through the furnace at once at a speed sufficient to allow the wire to be heated to the correct temperature to produce the required tensile strength, maximum toughness in the steel, and the correct grain structure. A typical town's-gas-fired patenting furnace of this size will treat 2,450 lb. of wire per hour on a gas consumption of 120 cub. ft. of 500 B.th.u. per 100 lb. of wire or 2,900 cub. ft. per ton.

Control in the hardening of tool steel is not so much a refinement as a necessity, and this important factor is emphasised in the "Hump" furnace of the Integra Co., Ltd. In these furnaces the rate of heating is under automatic control by means of the temperature difference between the work and the furnace. The rate of heat supplied to the furnace chamber is controlled by the rate at which the work takes up heat, thus the work itself is the essential guiding factor. When the steel under treatment is heated to its critical temperature the special chart associated with this furnace clearly indicates the change, and when the transformation is complete the curve on the chart informs the operator. An important feature of the curve is the hump formed between the two critical points, from which the furnace derives its name; quenching is carried out when the curve reaches a predetermined distance above the end of this hump. "Vapocarb" atmosphere protects the carbon in the surface of the steel, and the work leaves the furnace in a very clean condition.

Many heat-treatment furnaces are designed as special purpose furnaces, and in this category is the furnace shown in Fig. 17. Several vertical forced air circulation furnaces of this type, for the solution heat-treatment of light alloy aircraft sections, are being constructed by Electric Resistance Furnace Co., Ltd., for the Reynolds Tube Co., Ltd. It has been found that during the quenching operation a severe distortion of the sections occurs, and in many cases the subsequent straightening is considerable and very difficult on account of the hard nature of the material and the special shape of many of the sections. To eliminate this distortion, the furnace illustrated was tried as an experiment. In this furnace, the sections are suspended individually, and after heating are lowered into the quenching tank through the bottom door of the furnace. It was found that with this equipment distortion during quenching was practically eliminated, with the result that for the manufacture of some of the special sections now required a battery of these furnaces is being installed. This furnace is particularly useful for extruded tubes.

Designs of continuous furnaces vary considerably, and depend upon the type of work to be treated; many are of the box type, with some form of conveyer, but a rotary hearth furnace by Manchester Furnaces, Ltd., for continuous treatment of parts is an interesting type. Fired by gas or oil, installations of these furnaces range from 7 ft. 6 in. to 15 ft. diameter, with rotating hearths from 1 ft. 6 in. to 4 ft. wide. They are designed for temperatures

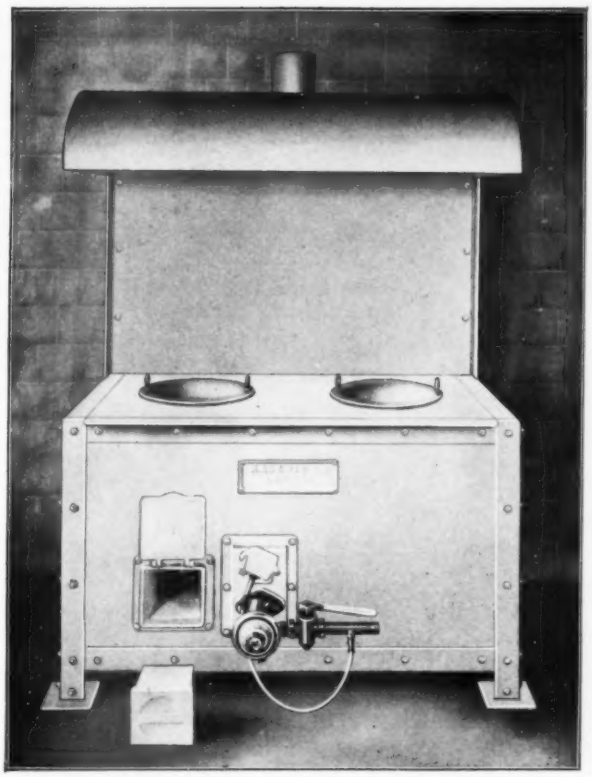


Fig. 21.—Kasenit two-pot salt-bath furnace for temperature ranging from 150°–900° C.

up to 1,150° C. Another interesting design is that shown in Fig. 18. This illustrates a battery of four "Birlec" pusher continuous type recuperative annealing furnaces, built in pairs for economy of floor space, for annealing brass components in a well-known Government factory. The furnaces are of the horse-shoe type (i.e., work enters along one side of the chamber, crosses over to the other side, and returns for discharge at the same opening) rated at 140 kw. each, and each capable of an output of approximately 1½ tons of material per hour. The pusher mechanism is hydraulic and controlled by an automatic sequence-timing device.

A new application of atmosphere control during heat-treatment concerns the heat-treatment of magnesium alloy castings, etc. For this purpose typical cylindrical forced air furnaces as used by many light alloy manufacturers, but a number of these furnaces, recently supplied by Electric Resistance Furnace Co., Ltd., are constructed as gas-tight units and are provided with a gas plant to supply an atmosphere of burnt town's gas with which the heating

Fig. 22.—A two-stage fired, two-zone controlled salt bath for the solution treatment of light alloy sheets.

Courtesy of Incandescent Heat Co., Ltd.

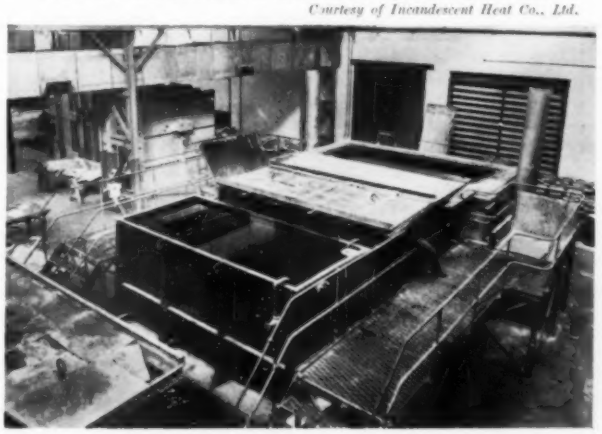


Fig. 20.—An electrode salt bath of the "Efco" Ajax-Hultgren type.

chamber is filled during the whole heat-treatment cycle. The provision of this inert atmosphere eliminates the possibility of inter-crystalline corrosion which is likely to occur with magnesium alloys during heating. Several installations of this kind are in service in the works of a number of the leading magnesium alloy casting manufacturers, and similar equipment is in course of construction for other works.

A double-ended nitriding furnace is shown in Fig. 19, the chamber dimensions of which are 22 ft. long, 5 ft. wide, and 2 ft. 6 in. high. It is fitted with two internal doors, enabling the furnace to be used as one, two or three separate units. Rating is 100 kw. in three separately controlled zones. Idler rollers are fitted both in the hearth and on the charging tables, the latter having winding gear for conveying the nitriding boxes in and out of the furnace.

Some of the most interesting developments associated with heat-treatment furnaces are connected with salt-bath equipment, particularly that for the treatment of light alloys. Recent installations include electrode salt baths of the "Efco" Ajax-Hultgren type, which can be applied for any salt-bath heat-treatment, including the solution heat-treatment of light alloys at temperatures round about 500° C. up to temperatures of 1,350° C. for the hardening of high-speed steel. One of the most outstanding points of this equipment is the reduction possible in heat-treatment costs when operating the bath as a cyanide hardening furnace. It is well known that, with cyanide furnaces, the pot costs are a problem, and because of the short life of the usual cast or pressed steel pots, recourse has been made to more expensive ones in various heat-resisting alloys, the result of this has been that the pot life has been increased to something of the order of six months, but only by considerable expense. With this electrode furnace, however, the normal pot life is about one year, and in many cases this has been exceeded, and what is even more remarkable is that this is obtained with a pot of plain mild steel. An illustration of this plant is shown in Fig. 20.

The heating in the electrode salt bath is very rapid and uniform, due to the automatic stirring of the salt brought about by special electrode design. Whether it is due to this stirring action or to some other feature is not known, but it is interesting to note that both in the U.S.A. and here it is claimed that work treated in the electrode cyanide salt bath has a greater hardness than similar work treated in a cyanide bath fired by other means.

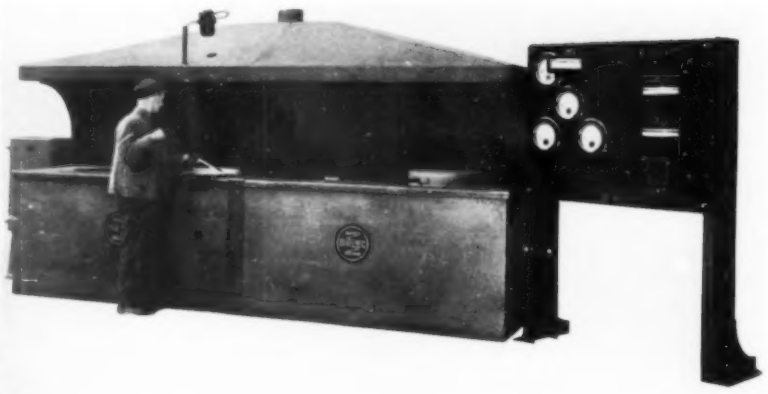


Fig. 23.—A composite electric furnace for hardening high-speed steel.

A number of twin-chambered, salt-bath furnaces designed and constructed by Kasenit, Ltd., have been installed in a large automobile works. Two preheating chambers are incorporated in the design, and town's gas is the heating medium. A rectangular type of salt bath by this firm gives very satisfactory service. It is an open-top furnace, and lead or salt bath may be used. A familiar type is the two-pot salt-bath furnace shown in Fig. 21. One of the pots is used for preheating the charge. The pots are 24 in. deep and 12 in. diameter. This furnace is used for the heat-treatment of either ferrous or non-ferrous components at temperatures from 150°–900° C.

The illustration shown in Fig. 22 is of a high-production gas-fired solution treatment unit supplied to one of the largest light alloy rolling mills in this country for normalising Duralumin sheets. The installation comprises a two-stage fired, two-zone controlled salt bath, 12 ft. long × 4 ft. wide × 5 ft. 6 in. deep, and quenching, washing, and sheet-handling equipment. The bath will take sheets up to 10 ft. long × 4 ft. wide in loads up to 15 cwt. per charge. It is equally suitable for large press work, fairings, and wing covering. Working temperature range up to 650° C., with maximum variation of plus or minus 3° C. Automatic temperature control and recording equipment in accordance with A.I.D. requirements.

The method of charging the sheets is an exclusive feature, and permits almost continuous operation. The sheets to be treated are suspended from the underside of the salt-bath cover, the latter being fitted in a special charging rack for this purpose. This rack accommodates two covers, the method of operation being that one cover can be loaded while the other cover, with sheets attached, is being treated, quenched and washed. By this method, the salt bath is kept in continuous operation, and heat losses due to the bath being uncovered are reduced to an absolute minimum.

A salt-bath "Cassel" furnace, has been specially designed for carburising Diesel engine camshafts. The pot is 15 in. diameter and 72 in. deep—a size which indicates the trend of the molten salt-bath method of heat-treatment for ferrous metals. An interesting development for the hardening of high-speed steel is the composite electric furnace shown in Fig. 23. It consists of four units—a circulating air pre-heating furnace, running at approximately 400° C.; a salt-bath furnace of the electrode type for pre-heating high-speed steels to approximately 900° C.; a carboneutral furnace, also heated by immersed electrodes and operating at temperatures up to 1,380° C.; and an external resistance furnace containing a molten salt-quenching bath, which can also be used for secondary hardening.

Potentiometers as a Means of Temperature Measurement and Control

By W. R. L. Kent, B.A., A.M.I.E.E., A.M.I.Mech.E.

Uniform temperature in a heat-treatment furnace is necessary to facilitate the uniform heating of components undergoing heat-treatment. One of the methods of measuring temperature and effecting its control in the furnace chamber is discussed in detail, and it is stated that the simpler the type of control, capable of being used successfully, the more desirable it is.

RELIABILITY and accuracy are the two most important considerations governing the choice of a temperature controller. Besides these, appearance, constructional finish and accessibility of mechanism, with resultant ease of maintenance, are points which must also be taken into account. Modern development in the metallurgical field tends to promote the use of an instrument which has the minimum possible sources of error and unreliability, and it is for this reason that the potentiometer is becoming more popular amongst instrument users.

The potentiometer instrument utilises the balancing of a potential against the thermocouple e.m.f., usually accomplished by means of a mechanical or electrical relay arrangement, for measurement purposes. The great advantage in this system of measurement is that the galvanometer is used only to determine the balancing position : thus any changes in galvanometer characteristics can be ignored, since the accuracy is unaffected.

A Potentiometer Circuit

A potentiometer circuit is illustrated in Fig. 1. A potential due to the batteries occurs between the points X and Y, and this opposes the thermocouple potential which is applied through the galvanometer and the switch K. When the two potentials are unequal, the galvanometer is deflected, and the relay arrangement is used to move the point X along the slide-wire resistance S until balance is restored. The position of the point X is thus the direct measure of the e.m.f. of the thermocouple, and hence of the temperature. The cold junction compensation coil N is so adjusted that it varies the potential difference from X to Y as the cold junction temperature changes ; the amount of variation being exactly sufficient to balance the variation of the thermocouple e.m.f. caused in the same way.

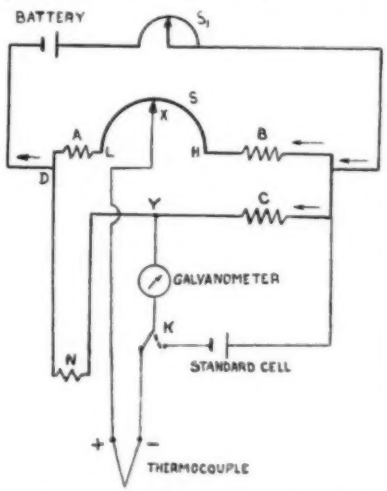


Fig. 1.—Showing a Potentiometer circuit.

In order to ensure that the current, which is present in the potentiometer circuit, and on which accuracy of measurement depends, is always maintained at the correct value, automatic checking is periodically arranged. In this way the galvanometer is periodically switched so as to be connected in circuit with the standard cell which opposes a known potential drop across the fixed coil C. The rheostat S^1 is then adjusted until no deflection of the galvanometer occurs, and the current value is thus corrected.

The Millivolt Type—A Comparison

In comparison with this, the direct deflectional or millivolt type of instrument depends entirely upon its galvanometer, which is calibrated directly in temperature, for accurate measurement. In the absence of any auxiliary source of power, the galvanometer pointer is, moreover, the only means for indicating the temperature or effecting control adjustment.

So as to assist in meeting these conditions, millivolt instruments are designed with galvanometers having as much power as possible. This is generally achieved by the reduction of the air gaps between the coil and magnet faces to a minimum, and by making the pointer or pen movement very light. Even under these conditions consistent accuracy of the instrument is often problematical, as the calibration of the galvanometer is affected by the accumulation of dust or particles of dirt. Moreover, maintenance of characteristics is absolutely essential if errors are not to be introduced.

A further argument in favour of the potentiometer instrument for measuring purposes is the means by which temperature compensation is accomplished. In millivolt instruments a spiral bi-metallic strip which is arranged to vary the zero setting of the galvanometer pointer is generally used ; it must be assumed that no ageing or change in resilience of this spring occurs, if reasonably accurate compensation is to be maintained.

On the other hand, the potentiometer offers a positive means of compensation by means of a coil wound with nickel wire, N in Fig. 1. This coil can be placed either in the instrument or at any convenient cold junction between the instrument and the thermocouple, and is unaffected by ageing or atmospheric conditions.

All users of instruments will be aware that one of the most important conditions which governs the satisfactory operation of any control mechanism is that adequate power shall be provided for operating the means which will effect adjustment. In the millivolt type of instrument, the control adjustment must be effected through the position of the galvanometer pointer, and since the power available for maintaining the pointer stationary is very small, the arrangement for cutting in and out of the control switch must be such that no load is imposed on the pointer, although its position be taken as the criterion.

The potentiometer is subject to no such limitations, since adequate power for operation of the control switches is available through the relay movement which is used to balance the circuit. For this reason the potentiometer is more satisfactory than the other type of instrument, from the point of view of control as well as measurement.

Two-Position Controllers

For the majority of furnace work it is general to supply temperature controllers of a two-position type, so that the source of heat is either full on or full off. A typical "on-and-off" control circuit for gas furnaces is shown in Fig. 2. The control contacts are arranged to operate a reversible motor through relays, so as to open and close the valve in the gas line. These relays can be dispensed with, providing the instrument contacts can be relied upon to carry

the necessary current without any detrimental effects.

By means of this simple arrangement control accuracy of within plus or minus 5° can nearly always be obtained, even with normal variation in loading, but a small constant fluctuation in temperature is bound to occur; this fluctuation is generally immaterial in treatment work, since the actual work temperature is usually maintained at an average with only a very small change. Apart from this, the radiation effects between the furnace walls and the work tend to even out the temperature changes.

In the case of gas furnaces of the natural-draught type, the gas control valve can be either of the motorised or solenoid type; a small pilot supply of gas is either by-passed round this valve, or permitted to pass through it when in the "closed" position, by means of limit-switch setting. If induction type burners are used, the control valve is placed in the air line.

Fig. 3 shows a diagrammatic arrangement of a furnace

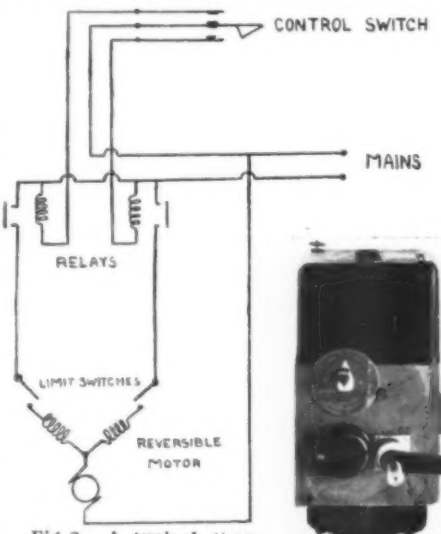
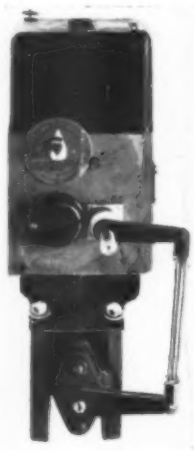


Fig. 2.—A typical "on and off" control circuit for gas furnaces.



The valve B operated by controlling mechanism.

The recording and controlling instrument at A.

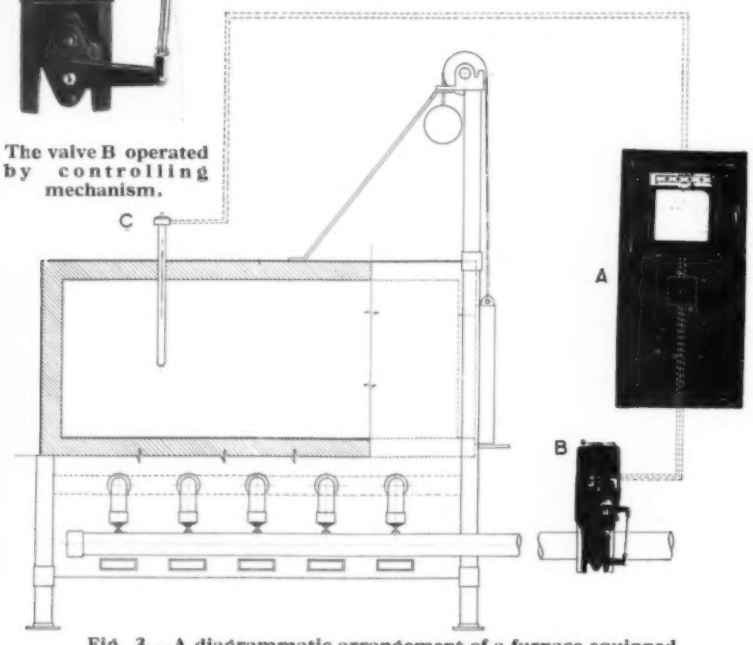


Fig. 3.—A diagrammatic arrangement of a furnace equipped with "on and off" or two-position control.

equipped with "on-and-off" or two-position control. The recording and controlling instrument A measures the temperature by means of the thermocouple C inserted either in the roof of the furnace, as shown, or through the back wall. The high and low contacts on the controlling mechanism operate the valve B, so as to open and close the gas line. This valve is provided with limit switches, to enable setting of the minimum and maximum quantities of gas, desirable for reasons described below.

By increasing the pilot flow to the furnace, it is often possible to reduce the additional flow of gas which is introduced when the automatic valve opens, and thus the relative rate of heating and cooling in the furnace under control. Similarly, a manual valve is sometimes placed in the gas line in series with the automatic valve, or a limit switch on the automatic valve is used, to adjust the quantity of gas passing to the furnace, when the automatic valve is open. By these two means, the rate of heating and cooling can be adjusted so that the temperature fluctuations in the furnace, as the automatic valve opens and closes, are not too severe. The setting of these valves will depend upon the conditions of gas pressure and loading in the furnace, and will change when these conditions vary.

On furnaces of the continuous type, it is generally possible to use manual valves for "pilot" and "top setting," as the valves can be adjusted during the soaking period, and since the conditions of loading do not vary appreciably, should not require any further attention. In the case of batch furnaces, however, where the heat absorption and consequent rate of heating with identical heat inputs may vary, readjustment of the quantities of gas passing either manually or automatically is necessary.

Automatic adjustment of the pilot and maximum gas flow can be accomplished by various means; typically by the inclusion of a third position of the valve or a "floating" feature. In the first instance, the valve is allowed to take up a third position between fully open and closed, directly the control temperature is reached. In this way the rate of heating is curtailed, and a better control obtained. Alternatively, the valve may be permitted to float or move slowly, following the variations in temperature, once the control temperature has been reached. This arrangement is, however, only suitable for furnaces having a reasonably constant loading.

In some furnaces with separate oil and air, or gas and air supplies, a single motorised gearbox is used to operate the two valves through linkage. Where two valves are thus connected by links, they are usually of the butterfly type, providing that the control is of the straightforward two- or three-position arrangement. However, should a more complex form of control be used, necessitating additional intermediate positions, valves giving a straight-line relation between degree of opening and flow, such as the parabolic plunger type, are often used; this assists in maintaining the correct fuel/air ratio.

In electric furnace work the simple two-position control is arranged to cut out all the elements through the contactor relay. It is sometimes usual to introduce the third position, in which half or part of the elements only are energised, and in this way reduce the temperature fluctuations which occur. A further means of ensuring a better control is by voltage regulation or interruption of the heating current, and for this purpose special units are supplied.

It is common practice to arrange for large gas or electric furnaces to be divided up into different "zones," each being separately controlled by one or more instruments.

Contact Mechanism

Before going on to consider the difficulties which temperature controllers must compete with, it is as well to mention the important part which the contact mechanism on the instrument must play. Any insensitivity or uncertainty in the operation of these contacts will greatly affect the closeness of control which can be obtained with two-position or three-position types; therefore control contacts should be designed to operate as fast as possible, and once "made," should not be allowed to "chatter." The power necessary for operation should be a minimum, although in the case of a potentiometer, this is less important since there is usually an ample margin over that required.

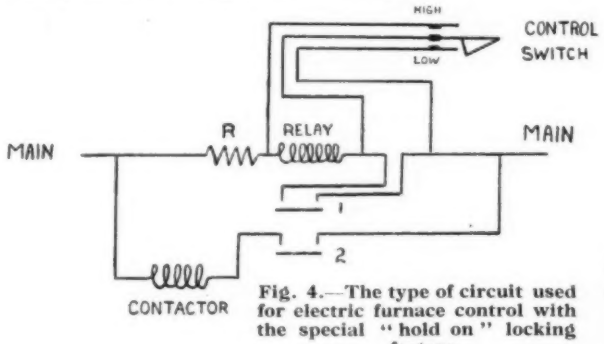


Fig. 4.—The type of circuit used for electric furnace control with the special "hold on" locking feature.

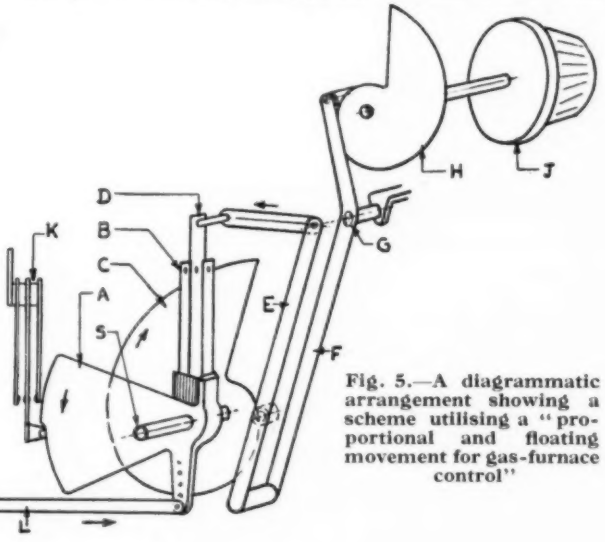


Fig. 5.—A diagrammatic arrangement showing a scheme utilising a "proportional and floating movement for gas-furnace control"

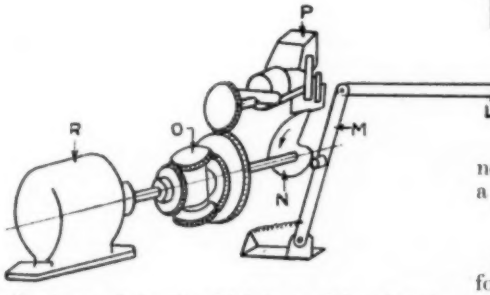


Fig. 4 shows the type of circuit which is used for electric furnace control and has the special "hold-on," or locking feature, which prevents any possibility of relay or contactor "chatter," with the consequent damage to mechanical parts and burning of contacts.

The arrangement is such that when the low contact is made the relay coil is energised, thus "making" the relay contacts 1 and 2. No. 1 contacts complete the circuit through the relay, which will thus remain energised if the low contact should tend to "chatter." No. 2 contacts complete the circuit to the electric furnace contactors, or alternatively to the furnace-heating elements.

Immediately the temperature rises above the desired value, the high contact makes, short-circuiting the relay coil, and opening the relay contacts, thus cutting off the heating to the furnace, and the maintaining effect of No. 1 contacts. The resistance R is placed in series with the relay coil, so as to prevent a short circuit to the mains supply when the high contact makes.

Insensitivity of measurement or control, such as that which results from poor design of control contacts, would introduce a "dead zone" effect, so that there would be an appreciable delay between the point of measurement and the subsequent point of adjustment. Any such time delay, whether due to this or due to conditions outside the care of the controlling instrument, may complicate the problem, and prevent the use of a simple form of controller, such as two- or three-position types which have been mentioned, and necessitate a scheme which includes some form of "anticipatory" or "proportional" correction.

It is therefore necessary when considering the type of controller most suitable for any particular application, to take into account not only the variations in actual loading conditions in the furnace, but also any time delay which is likely to be present. A "time lag" will often be introduced entirely apart from the controller, owing to large thermal capacity of the furnace, or excessive heat insulation between the source of heat and the thermocouple. For this reason it is extremely difficult to make an accurate forecast of the closeness of control which can be obtained with any particular type of instrument, when these factors are present.

Generally speaking, there is a limiting condition in which the more simple form of control will not be satisfactory. In this case, although the variation in load could normally be met, the "time lag" which exists would result in a greatly increased "overshooting" of the temperature.

Proportional Control

For gas-furnace work, there are a number of different forms of controllers which can be used to maintain the temperature fairly closely in instances such as these. Of these, the "proportional" or "throttling" type is one of the most common, in which the control valve moves proportionately to temperature variations. A further form is the multi-position control, being merely a form of "proportional" control, in which the valve moves in steps instead of continuously. This feature is sometimes known as automatic "reset" or "droop" correction.

Fig. 5 shows a scheme utilising a "proportional and floating" movement for gas-furnace control. A "proportional" controller is very satisfactory when dealing with large variations in temperature, but suffers from the limitation that valve movement occurs only so long as the temperature is varying. If at any time the temperature should settle down at some value away from the control point, due, for example, to a variation in heating values in the furnace, then the valve would remain in that position, with the result that there would be a tendency for the temperature to wander; the degree to which this may occur depends on the "throttling" range—i.e., the temperature

variation which must occur before the valve moves to full travel in either direction. Where an appreciable time lag exists it is often necessary to increase the "throttling" range, so as to prevent "hunting," and in this way the danger of "temperature wander" is greater.

This disadvantage of the "proportional" controller can be overcome by the addition of a "floating" movement to the valve, which is continuously attempting to restore the temperature to its correct value, and prevents the occurrence of any wandering.

In Fig. 5 the "proportional" movement is arranged as follows: The shaft S moves in relation to the variation in temperature as measured by the instrument. On this shaft is a cam C, and when the cam moves it alters the position of the link E, and thus the centre contact of the switch B. In this way, one or other of the contacts of the switch is made, and this immediately begins to move the control valve. The control valve has a Selsyn motor fitted to it, and the movement of this Selsyn is reproduced by the motor R, rotating one side of the differential O. When one side of this differential is rotated, the switch D breaks, owing to the movement of the links L and M from the cam N; thus the "proportional" movement of the valve is achieved

The additional "floating" movement is superimposed on the above arrangement by means of the movement of the sector A, which is integral with the switch B and loosely mounted on the shaft S. When the Selsyn motor R reproduces the valve movement, the sector A is moved so as to make one or other of the contacts of the switch K; this switch operates a small reversal motor P, which drives the other side of the differential O, tending to unbalance the switch B, and cause one or other of the contacts to make. In this way the required additional movement is given to the valve, always tending to bring the temperature back to the control value.

The setting of the temperature at the required point is accomplished by means of a setting scale and pointer (not shown), and knob J, by means of which the cam H is moved. Movement of the cam results in the links E and F moving the centre contact D of the switch B, so that the valve moves to a new position.

Generally speaking, the simpler the type of control which can be used with success for any particular application, the more desirable it is. For this reason the two- or three-position arrangement is adapted in roughly three-quarters of the field. Therefore, for the majority of cases the potentiometer instrument which is especially suitable for the operation of "make-and-break" contact mechanism, provides the most satisfactory solution. In this way it is possible to obtain the closest control consistently with the maximum reliability and minimum maintenance.

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Refractories for Heat-Treatment Furnaces

Specially Contributed

Improvements in furnace plant are expected to result in longer life and greater efficiency, and the demands on the refractories used are increasing in consequence. Brief information on this important subject, given in this article, shows how the responsibilities are being met.

FURNACES for the heat-treatment of both ferrous and non-ferrous metals now cover a variety of designs, and while much information is available regarding the furnaces from a mechanical and metallurgical point of view, information dealing with the refractories aspect of heat-treatment furnaces appears to be somewhat neglected.

Heat-treatment covers a wide range of temperatures, ranging from the heating of steels from 200° C. to 750° C. for tempering; 750° to 1,330° C. for hardening, and the cooling and/or quenching in mediums of air, water, oil, lead and salts. Developments in high-speed steels have necessitated the use of temperatures in excess of 1,300° C. This tendency has, therefore, imposed increasingly heavy duties upon furnace refractories.

During recent years, much has been done in the way of increasing efficiency of heat-treatment plant. This has been accomplished by improved burners and flue layout, and consequent complication in furnace design. Such improvements have involved greater initial expense, and this, in turn, has resulted in the user of heat-treatment plant expecting better service in both life and efficiency. In meeting these requirements, the structural part of the furnace and the firing medium have presented little difficulty as compared with the refractory requirements, and it is safe to say that by far the greater responsibilities resulting from the improvements in design have fallen to the lot of the refractory manufacturer.

General Refractory Considerations

In being consulted on problems relative to heat-treatment furnace refractories, the refractorer would do well to ask and obtain precise information from the furnace engineer on such questions as the following :—

(1) What is the maximum temperature reached in the furnace ?
(2) Is the furnace temperature recorded—that is, are pyrometers or full temperature recording apparatus fitted to the furnace ?
(3) Is the furnace atmosphere controlled ?
(4) What class of firing is in evidence ?
(5) Is the layout of the furnace practicable, particularly on the stresses imposed upon the refractories by way of arch design, flue design, etc. ?

Answers to these and other questions which could be cited result in providing the refractorer with tangible information to assist him in refractory recommendations. Question (4), for instance, is important, in so far as the particular class of firing incorporated in the furnace design will most probably govern the type of refractory lining to employ. It is not intended here to enter into any controversy as to the relative merits of, say, the electric, gas, oil, coal and pulverised fuel systems of furnace heating, but suffice it to say that each has its own particular advantages, yet each gives rise to specific considerations from the refractory angle. With electric heating from elements no furnace flue brickwork considerations are necessary, while from gas-firing it is by no means uncommon to experience peak temperatures periodically in the furnace near the burners, with a resultant localised fusing of the brickwork. In such case, of course, a refractory of sufficiently high duty will be necessary in and around the burners. Pulverised fuel firing, for instance, gives rise to high temperatures in the combustion chamber, and consequently requires the special attention of the refractory supplier. In turning from these sketchy observations to a discussion on the types of refractories employed in heat-treatment furnaces, it is convenient, in the first place, to refer to firebricks.

Firebricks

Firebricks, varying in Al_2O_3 content between, roughly, 32% and 42%, are employed universally for lining heat-treatment furnaces, although there are signs which indicate that ordinary firebricks will not necessarily hold pride of place in the future.

In the continuous type of heat-treatment furnace, it can be said that a good quality firebrick lining is all-sufficient, seeing that these firebricks are not subject to any rapid temperature fluctuations. It is imperative, however, that the qualities of firebricks used are selected carefully and the lining graded along the furnace. That is, in the cooler, less important parts of the furnace a normal class of Yorkshire or Stourbridge firebrick will suffice, but in the hotter and actual metal-treating zone, a higher class aluminous brick is advisable, of the Scottish 42% Al_2O_3 range, depending, of course, upon the maximum temperature.

The manufacture of firebricks has made rapid strides during recent years, and several manufacturers are now producing firebricks characterised by extremely dense structure, hard firing, and high vitrification, together with accuracy of size and shape—all of these factors being highly desirable for use in heat-treatment furnaces.

Where firebricks for furnaces working intermittently are under consideration, one of the main points to consider is the refractory's resistance to spalling. Intermittent heat-treatment furnaces, especially if they have a short cycle, impose physical stresses on firebrick linings due to constant heating and cooling. Few firebricks are capable of withstanding such repeated temperature changes without ultimate spalling failure. The spalling tendencies of firebricks have engaged the serious attention of more than one refractory manufacturer during recent times, and it has now become the practice to include a fairly high percentage of grog in the brick batch to produce firebricks that are more elastic in character and offer increased spalling resistance when used in periodic heat-treatment furnaces.

Mention was made earlier to the importance of using hard-fired firebricks in heat-treatment furnaces. By high-temperature kiln-firing during manufacture a state of affairs is ensured whereby no free iron is left unconverted in the firebricks. It is known that reducing furnace atmospheres are far from kind to firebricks, showing traces of free iron, for reaction occurs between the gases and the iron nuclei, with a consequent shortening in the life of the firebrick.

It should be noted before concluding the remarks on firebricks that high alumina bricks, with Al_2O_3 contents of 50% to 60%, are gaining popularity for heat-treatment furnace purposes, one of the chief types of these high alumina bricks being sillimanite.

Sillimanite

Sillimanite possesses numerous properties which render it an admirable refractory for lining heat-treatment furnaces, especially those working intermittently and requiring a quick cycle for ferrous products.

The outstanding characteristics of well-made sillimanite

bricks are (1) a refractoriness—under-load figure of 50 lb. per sq. in. at 1,710° C.; (2) negligible and perfectly uniform after-expansion; (3) remarkable resistance to spalling. Perhaps feature number (1) is not so important as numbers (2) and (3) for heat-treatment furnace considerations. Sillimanite presents no critical temperatures during heating up, thereby making it possible for the furnace to be elevated to treatment temperatures in the minimum possible time. Sillimanite may also be cooled down equally quickly without any qualms being entertained on the grounds of cracking or spalling. That a quicker furnace cycle will be possible through sillimanite permitting of rapid heating and cooling will be readily appreciated. The after-expansion of a well-burnt sillimanite brick is roughly 0·04% for every 100° C. rise in temperature, and this value is considered so small as to make it possible to eliminate the use of any expansion joints to the furnace lining.

The spalling resistance of sillimanite is little short of phenomenal, as will be gathered when it is recorded that the stringent heating and cooling operations mentioned immediately above have no adverse effects on the bricks.

For certain types of heat-treatment furnaces, sillimanite linings have undoubtedly come to stay, and although such a refractory is expensive to purchase (roughly, £72 per 1,000 for 3-in. squares), its extended use can be confidently expected in the future. Incidentally, sillimanite presents an excellent proposition for such parts of the furnaces as burner blocks, pyrometer tubes, sighting plugs, etc.

Insulating Bricks

These are days when furnace engineers are devoting careful thought to the problem of furnace efficiency and fuel economy, and insulating materials are accordingly being more resorted to as a means of achieving the desired ends.

Most heat-treatment furnace operators are acquainted with the diatomaceous grade of insulating brick and depending on the types of refractory lining used, so a correct grade of insulating brick should be chosen. There does exist a dislike on the part of some furnace people to insulate refractory linings, particularly firebrick: this dislike is clear to see, for insulation produces a higher mean temperature through the firebrick, and unless the brick is of good quality, softening of the matrix may result. The prejudiced attitude towards insulation is being overcome, and most heat-treatment furnaces are now being insulated.

Ordinary diatomaceous insulating bricks have definite limitations, however, for they are incapable of withstanding temperatures in excess of 850° C. Above this temperature the bricks begin to shrink and disintegrate. Thus, diatomaceous bricks can only be used with safety behind 9 in. or so of refractory lining in heat-treatment furnaces. With the recent developments and standardisation of high-temperature insulating bricks, a refractory is available which can be used successfully and efficiently for the actual furnace lining. High-temperature insulating bricks possess usually a china clay base, and are capable of remaining stable up to temperatures of 1,350° C. Further, the cold crushing strength of good high-temperature insulating bricks is approximately 275 lb. per sq. in., while the thermal conductivity of the bricks is about one-quarter that of firebrick at 1,000° C. (2·5 B.th.u. per sq. ft. per hour per 1 in. thickness per 1° F. for insulating brick, compared with 10 B.th.u. for 32/34% Al_2O_3 firebrick). These and other properties which could be instanced lead one to the conclusion that providing heat-treating in the furnace does not exceed, say, 1,250° C. (a margin of safety with the bricks is necessary), the lining of the furnace can be built in confidence with high-temperature insulating bricks. Some of the advantages claimed from the embodiment in the furnace of such a lining include: (1) Less thermal storage, and thus easier control of the furnace; (2) less thermal loss through the furnace walls, and thus appreciable fuel-saving; (3) absence of dead spots; (4) lighter furnace structure (high-temperature insulating bricks are roughly one-third the weight of firebricks); (5) more uniform heat.

High-temperature insulating bricks are not resistant to abrasion, so that care should be taken to see that the products being heat-treated are not allowed to fall on to the side walls or to set up abrasive action on the bricks.

Where heat-treatment furnaces have fairly thick hearths, these should, if possible, be divided into a primary and a sub-hearth, the latter being built of a refractory insulating concrete to prevent heat striking downwards into the furnace foundations or the atmosphere below the hearth, according to the class of furnace involved.

The remarks on insulation applicable to heat-treatment furnaces could well be extended, but it is hoped that sufficient has been written to indicate the avenues on which developments are being made.

Super Refractories

Under this heading may be placed such refractories as carborundum, fused-alumina bricks, zirconium, and others. These types have specialised use in a certain range of heat-treating furnaces, although the above super-refractories are at present so expensive as to make their use limited. The production of carborundum bricks is now well commercialised, although the manufacture of mullite and zircon bricks still leaves much to be desired. Expert advice is imperative on the selection of any super-refractory, for by reason of the high cost of the refractories (£120 or so per 1,000 for 3 in. fused alumina bricks) it is obviously a matter for most careful consideration.

Furnace Hearths

The hearths of heat-treatment furnaces, particularly those dealing with ferrous materials, are often subject to failure when constructed of firebricks. The principal reason for this is that an oxidising atmosphere is often prevalent in the furnace, thus causing subsequent scaling of steel. Reaction then occurs between the scale and the firebrick hearth, causing the formation of ferrous silicate on the furnace bottom.

To overcome this undesirable state of affairs, it is advisable to build the furnace hearth of a neutral refractory, that is, one which is not subject to either basic or acid attack. Chrome bricks are being used extensively as a neutral refractory for heat-treatment furnace bottoms, but there is a pronounced leaning, especially in America, towards the use of a plastic neutral ramming composition to replace chrome bricks.

These ramming compositions have much to commend them, and they bid fair to oust the use of chrome bricks for the furnace hearths. The neutral refractory compositions, of the chromite Plastic K–N type, have a decided advantage over chrome bricks. The former can be rammed into position to form a strong and extremely durable hearth. Unlike firebricks, no allowance need be made for either expansion or contraction when ramming up these compositions. However, in view of the comparatively new technique of drying and heating up of the chromite compositions under review, it is advisable for the furnace engineer to consult the refractorer.

With their air-setting characteristics, extreme denseness (about 200 lb. per cub. ft. when set), and durability, and resistance to scale attack, these neutral ramming compositions are likely to become the standard refractory for use in heat-treatment furnace hearths where temperatures are high and oxidising conditions prevail.

Jointing Cements

In the past insufficient attention has been paid to the question of jointing the brickwork in heat-treatment furnaces. In the case of firebricks, it is a still popular practice to joint the bricks with ordinary ground fireclay. The writer cannot deprecate too strongly this procedure both on the grounds of bad furnace practice and false economy.

Due to the comparatively low operating temperatures of heat-treatment furnaces generally prevailing, fireclay

(*Continued on page 38*)

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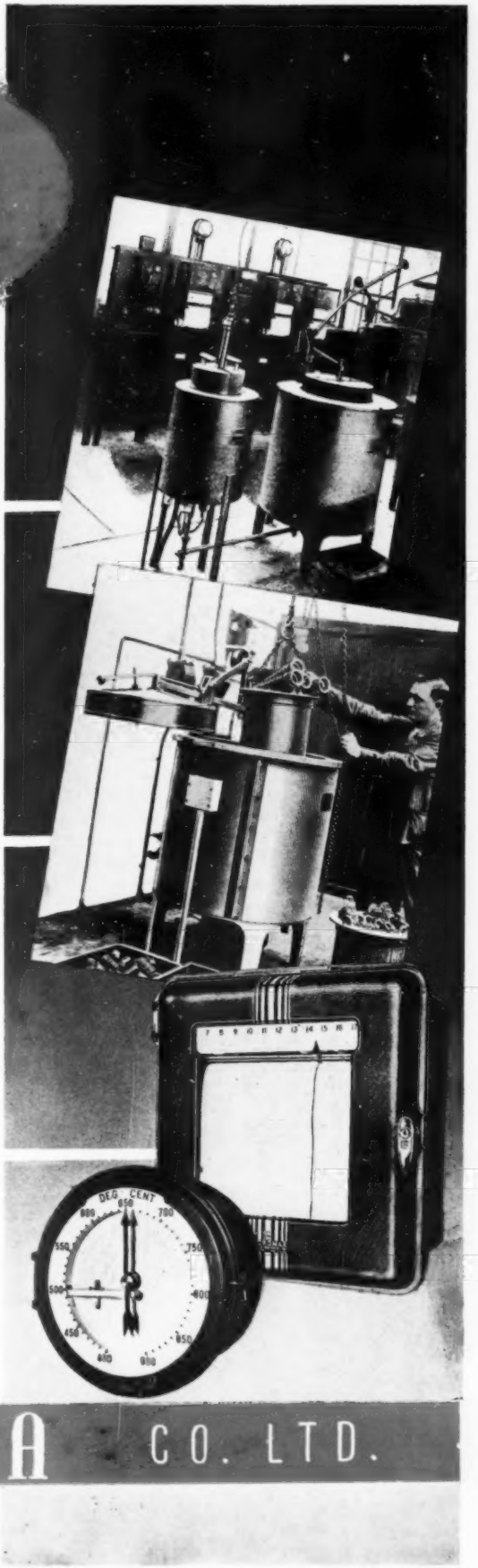

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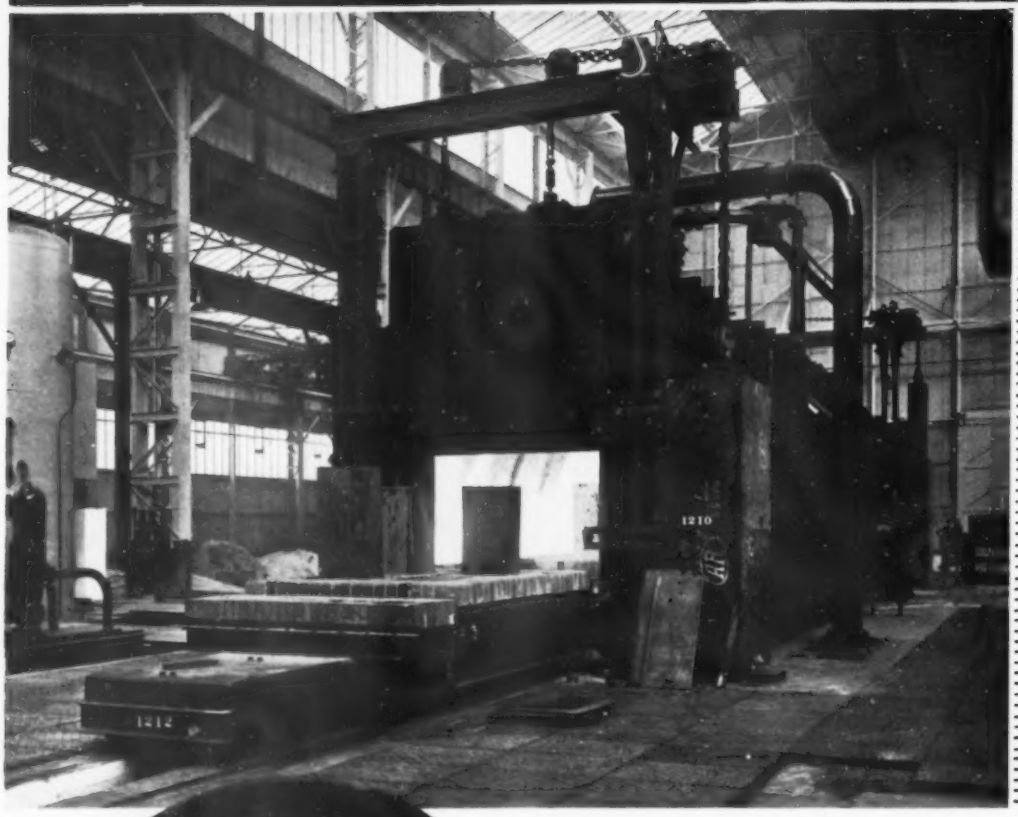

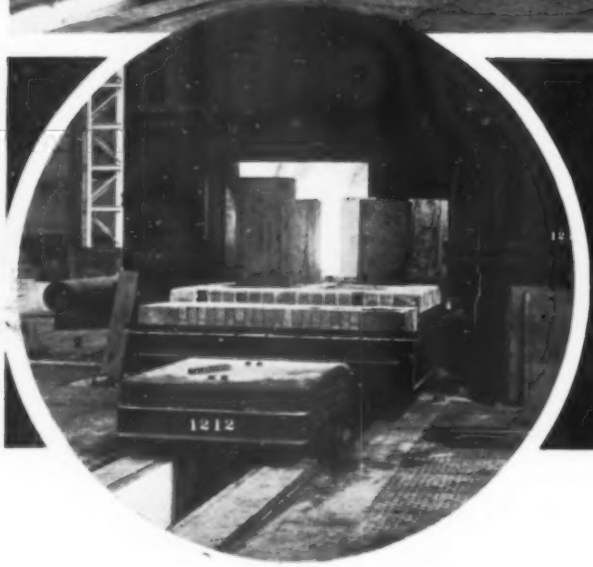

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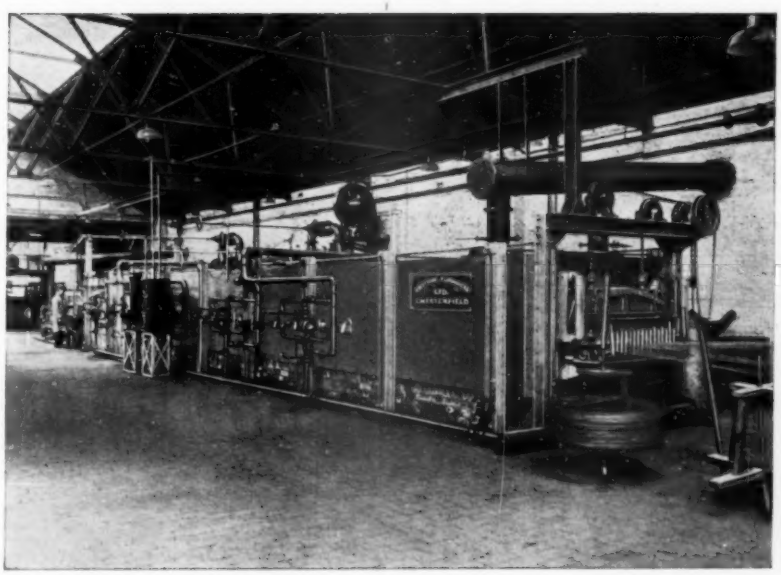

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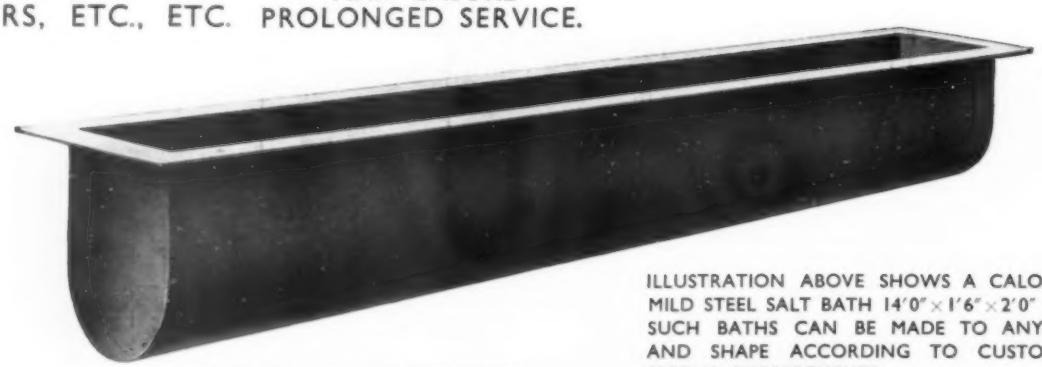

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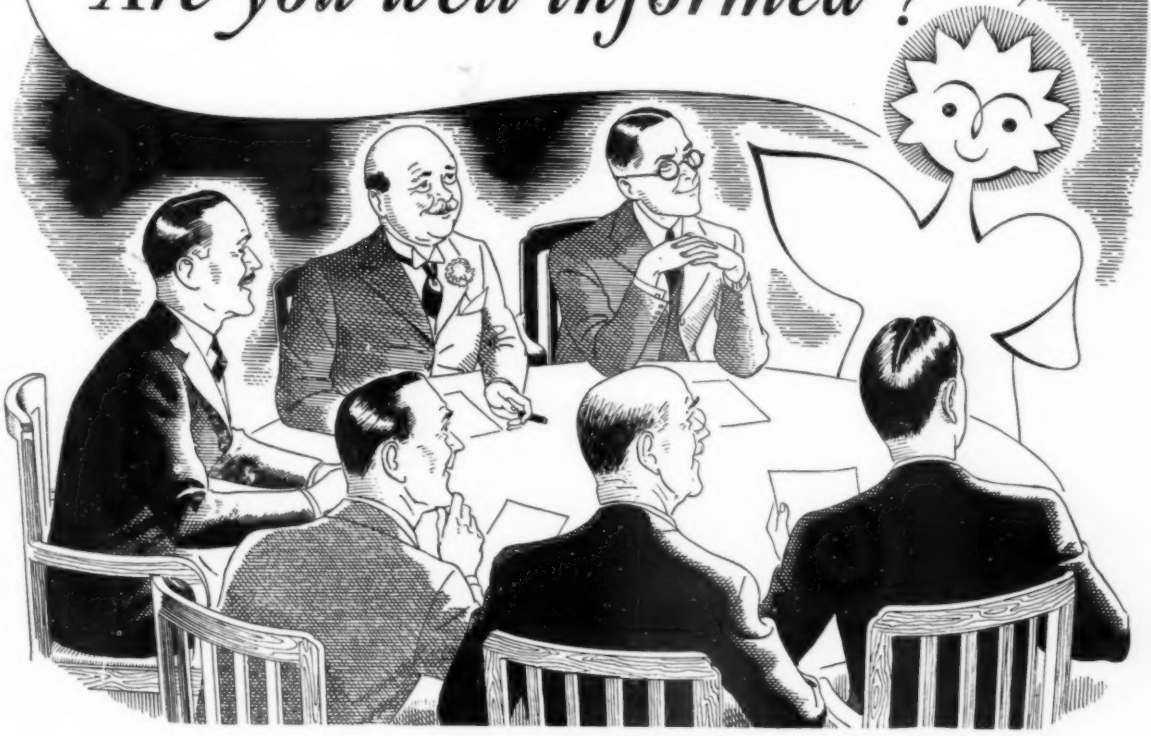

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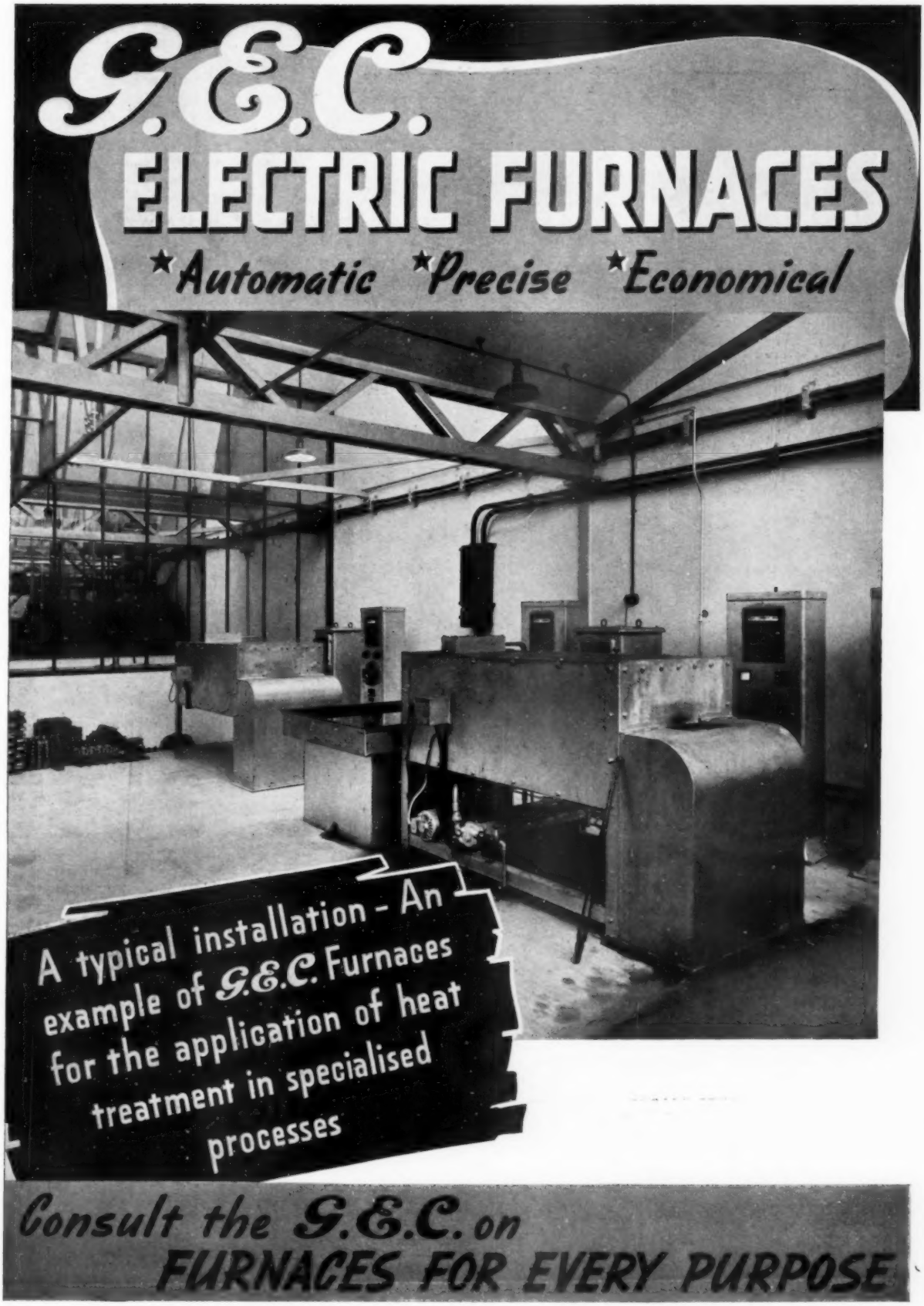
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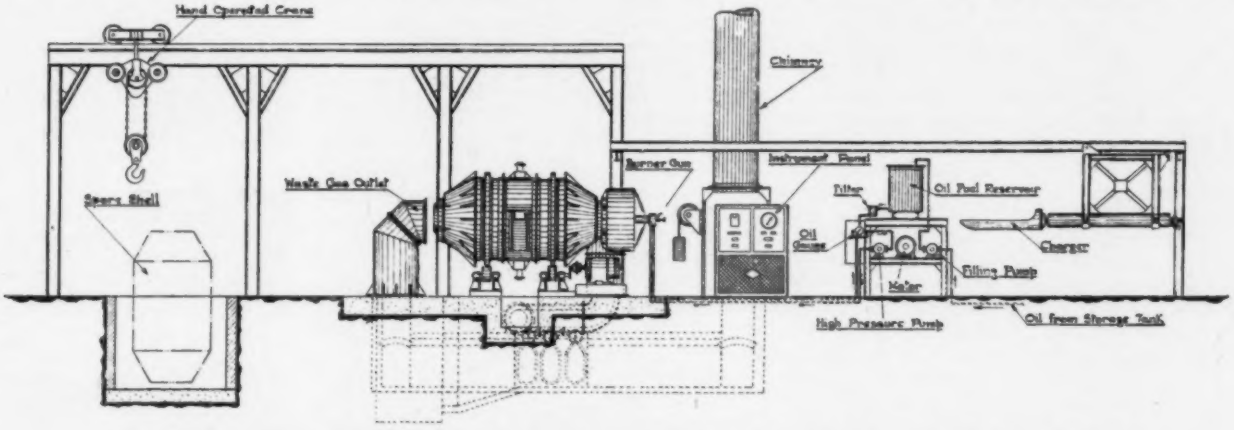
Recent Developments in Materials, Tools and Equipment

The "Fofumi" Rotary Melting Furnace

SEVERAL rotary melting furnaces have been developed in recent months, each possessing certain advantages when applied to iron foundries. A furnace of this type is now available for steel foundries which has several advantages. It is claimed to have a very low operating cost and also to possess the advantages of low oxidation, due to controlled atmosphere, the ability to make alloy additions to the melt without stopping rotation, and to remove samples whilst the furnace is operative. Known as the Fofumi furnace, it permits a view of the melting operation and requires no tilting for either charging or discharging. It is made by Messrs. King, Taudevin and Gregson, Ltd., of Sheffield, under Deblanchal patent.



The general arrangement of the Fofumi rotary hearth furnace designed after many years of careful research work on steel melting requirements.

Special steels can be worked—the initial charge is made to obtain a soft, or even extra soft, steel, and this is then deoxidised by first changing the slag and replacing the original iron oxide saturated slag with a new acid slag, then comes the addition of manganese, and, finally, by stopping the refining process through the addition of aluminium. The special elements are then added in the form of ferrous chrome, silicon or nickel, according to requirements, and the furnace operation is continued. Melting times are short: it is claimed that a steel charge of 5 tons can be poured in 2 hours after lighting up.

This oil-fired furnace can therefore be said to bring to steel melters the satisfaction previously enjoyed by iron founders using rotary furnaces. The chief characteristics are the shape and design of the burner, atomisation of the fuel, the quality of the refractory lining, simplicity of teeming and slagging operations, and facilities for sampling and correction.

The waste gases pass into a refractory-lined flue, in which gas eddying and lining wear are avoided as far as possible, and this flue leads to a recuperator composed of alloy steel tubes. Cold air is introduced to the recuperator by blowers, and the pre-heated air is passed through insulated tubing to the burner end of the furnace. The amount of this pre-heated air supplied to the furnace is regulated by an automatic temperature controller. Air is circulated in the recuperator when the furnace is stopped, avoiding excessive recuperator temperature.

The type of burner used is suitable for all heavy liquid fuel oils used in conjunction with air pre-heated to a high temperature. In the burner unit are two distinct parts—one for distribution of air and the other for injection and atomisation of fuel. Projection pressure is approximately 250 lb. per sq. in., which is sufficient to make the oil spray form a cone at the exit of the injector and produce an effective flame of about 1,800° C.; this flame can, of course, be modified as desired to suit the composition of the metal being melted. A mechanical charger operates on an overhead track, charging through a large hole uncovered by the swivelling of the fuel mixing chamber, whilst the furnace remains in a horizontal position.

As soon as ignition commences, the furnace is rocked slowly until the metal becomes plastic, and when that stage is reached, rotation of the furnace starts; the shell then rotating fully at a speed of 1 r.p.m., this resulting in the molten bath remaining level whilst the hot lining passes beneath it. Progress of the melt can be inspected through a mica window fitted in a small door in the fuel mixing chamber. It is through this door that sampling can be effected, and any additions to the charge made whenever necessary.

In regard to the furnace itself, it is built up of heavy steel plate with separate cone-shaped ends fastened to the cylindrical section by shackle bolts. These ends can easily be removed or replaced. A pouring spout, also removable, is bolted to the centre of the furnace shell in a position that enables the molten charge to be poured into any capacity ladle, the spout being turned into any desired position by rotation of the furnace.

The furnace shell can be lined with either a monolithic acid lining or a basic lining made of magnesite brick or of a special magnesite chrome brick. The rate of heating can be controlled within narrow limits, with no difficulty in repeating the settings for repetition work. Temperature of 1,750° C. can be attained within one and a half hours, if rapid heating is wanted.

It will be realised that the Fofumi is fundamentally a refining furnace. The refining quality of the flame is very soft, and permits pouring a charge comparatively low in carbon, silicon and manganese. Analyses of metals cast in Fofumi furnaces include the following three examples: Steel (C, 0·38; Si, 0·30; Mn, 0·70; S, 0·05; P, 0·06), Cast iron (C, 3·39; Si, 2·20; Mn, 0·62), and malleable iron (C, 2·37; Si, 0·72; Mn, 0·31). The melting time for the cast iron example was 60 mins., and the pouring temperature 1,480° to 1,500° C., the corresponding times for the malleable iron being 70 mins. for melting and pouring temperature of 1,550° to 1,600° C.

Reviews of Current Literature

Metal Spraying

SINCE the first edition of this book was published, some thirteen years ago, there has been considerable development in the application of the process of metal spraying and in the design of equipment used. Although its primary function in combating corrosion continues, a useful application, which is becoming of increasing importance, is the building up of worn parts of machinery which would otherwise need replacement. Apart from new applications, however, knowledge of the technique of metal spraying has advanced, and this second edition has been revised to incorporate new developments and improved technique.

Early attempts at metal spraying, which are described in the first chapter, conforms to the earlier edition, but Chapter II incorporates developments of modern spraying pistols with details of earlier apparatus designed for this purpose. The wire-fed pistol and its operation and maintenance is described in Chapter III ; this and Chapter IV are composed almost entirely of new data, particular attention being directed to sand-blasting, dust extraction, and the health of operators. The nature of sprayed metal which is discussed in Chapter V incorporates the results of considerable research which has been carried out since the first edition was published, and the information is presented in a useful manner. This chapter also contains an outline of the electrochemical nature of corrosion phenomena.

Remaining chapters compare the metal spraying process with other methods of metallisation, such as bronzing, firegilding, Sheffield plating, tinning, galvanising, Sherardising, aluminium coatings, electro-plating, etc., and applications of the process. In its new form, this book is a valuable work on a subject which has made great progress in recent years.

Second Edition, revised and largely rewritten by E. C. Rollason, M.Sc. ; First Edition, by T. Henry Turner, M.Sc., and N. F. Budgen, M.Sc., Ph.D. Published by Charles Griffin and Co., Ltd., 42, Drury Lane, London, W.C. 2. Price 18s. net.

Qualitative Inorganic Analysis

COMPARATIVELY little has been taught about qualitative analysis in this country, and it is even asserted that the present-day student, although well versed in organic and physical chemistry, knows less of qualitative analysis than his predecessor of 25 years ago. The objects of the two main divisions of chemical analysis—qualitative and quantitative analysis—are concerned with the detection and the determination of substances, respectively, and in many of the tests employed in qualitative work it is of little consequence whether the reactions proceed on quantitative lines or not.

These factors are adduced in this new book, in which a few organic acids are included, but these have been limited to such as are of direct importance to this branch of the subject. The author rightly points out that " rigid definitions of fundamental conceptions in chemistry are very difficult to formulate without complications arising as the science develops," citing the difficulty of stating whether certain changes should be regarded as oxidation or reduction, and quoting Remy's point that oxidation and reduction when considered in the purely chemical sense may be in conflict with electro-chemical definitions, as in the case of heat dissociation of calcium hydride.

The book deals competently with general principles—including colloidal phenomena—methods of qualitative analysis, reactions of the metals and of the acid radicals, systematic analysis of the metals (with notes on reactions and separations), and examination for acid radicals.

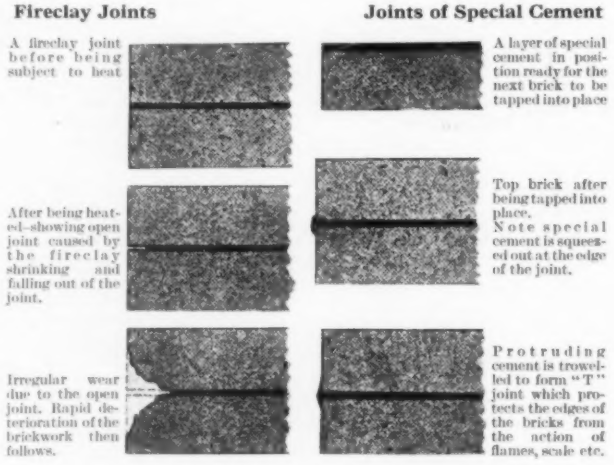
By A. J. Berry, M.A., published by the Cambridge University Press, Fetter Lane, London, E.C. Price 6s. net.

Refractories for Heat-Treatment Furnaces

—*Continued from page 36*

joints are far from vitrified and hence mechanically weak. There is also a considerable shrinkage in the fireclay, and consequently liability to fall away and leave the joints exposed. It is a well-established fact that the weakest part of almost every refractory structure is in the joints, and it is a short-sighted policy for the furnace builder to take pains in selecting a high-grade refractory for the furnace and finally to joint the bricks with a low-grade cement.

There are now available high-grade refractory cold-setting cements for jointing refractories of all qualities, and although these cold-setting cements are expensive, they make for a sound construction. These special jointing cements show a refractoriness in the region of 1,660° C., produce a rock-like hardness when set, and bind brickwork into what may be termed a monolithic whole. The sketches below are included to illustrate the nature of ordinary fireclay joints, compared with those produced by using one of the specially compounded setting cements.


Fireclay Joints
Joints of Special Cement
A fireclay joint before being subject to heat
A layer of special cement in position ready for the next brick to be tapped into place
After being heated—showing open joint caused by the fireclay shrinking and falling out of the joint.
Top brick after being tapped into place. Note special cement is squeezed out at the edge of the joint.
Irregular wear due to the open joint. Rapid deterioration of the brickwork then follows.
Protruding cement is trowelled to form "T" joint which protects the edges of the bricks from the action of flames, scale etc.

It is encouraging to note that an increasing number of furnace builders are turning to the use of these refractory jointing cements, doubtless realising that this policy provides the only means of producing a strong and durable structure to the refractory lining.

Furnace Design and Refractories Advice

Perhaps a word or two under the above heading would not be out of place. Question (5), given earlier under the heading of " General Refractory Considerations," suggested that co-operation is desirable between the heat-treatment furnace builder and the refractory manufacturer. It is essential for the latter to be *au fait* with full constructional details of the furnace, particularly when high efficiency is sought after.

Arch design, for instance, is a branch of furnace construction in which far too many refractory failures are reported. The fact is frequently overlooked that arches, and particularly low arches, give rise to very high compression stresses, and refractories must be carefully watched to see that they are sufficiently strong in compression at the working temperatures. Where insulation is incorporated in and around the throw of the arch, this must also be carefully watched, as insulating refractories are normally weak in compression at even normal temperatures.

Many other features of furnace design calling for refractories advice could be mentioned, and in all fairness it can be said that furnace constructor and refractorer alike are now adopting closer co-operation with the object of discussing and settling their mutual problems.

The Iron and Steel Institute

70th Annual Meeting

IN many respects this annual meeting of the Iron and Steel Institute was of an outstanding character, and in spite of many other urgent duties there was a good attendance of members. The meeting was especially noteworthy in the number and importance of the reports presented, which included the eighth report on the Heterogeneity of Steel Ingots; the second report of the Alloy Steels Research Committee, and the first report on Refractory Materials, and the valuable papers presented at the technical session.

At the opening meeting, the President, the Rt. Hon. the Earl of Dudley, M.C., welcomed the members who attended, and expressed his pleasure at seeing so many members from overseas, including representatives from America, Belgium, France, Germany, Holland, Luxemburg, Norway and Sweden, as well as members from India and the British Dominions. He particularly mentioned Dr. Paul Merica, and extended to him the sincere gratitude of the Institute for the part which he played in arranging the hospitality which was to have been extended to members of the Institute had they been able to visit the United States of America last autumn.

Presidential Address

Lord Dudley confined his address to a general review of progress, drawing attention to the fact that it was unusual for a president to serve a second year, which he had been very reluctant to do, but the Institute had issued an appeal in connection with its move into new offices, and with an attempt to place the finances of the Institute on a more stable basis, and since he had taken part in the preliminaries of that appeal, he felt it would be unfair to place the work on other shoulders before it was completed. The Institute now had, for the first time, a proper house to serve as offices and headquarters for its activities. All its activities were now being reorganised to make sure that all branches were as efficient as they could possibly be made.

Much progress had been made during the year in collective research for the industry, and the Institute's activities in that direction had increased very considerably. Two of the Vice-Presidents of the Institute, Sir William Larke and Dr. W. H. Hatfield, were chairmen respectively of the Iron and Steel Industrial Research Council of the British Iron and Steel Federation, and of the Programme and Finance Committee of that Council. These bodies are organised by the Federation to take charge of collective research for the industry, and the Institute is represented upon them. The Institute's four major Research Committees, which are Joint Committees with the Federation, had continued their work in a very active way during the year; two presented reports last year, and the reports of two were being presented at the present meeting. These Committees now had twelve or more sub-committees attending to special problems. The President warmly thanked Dr. Hatfield, who is chairman of three of those Committees, and Mr. Dawson, the chairman of the Steel Castings Research Committee, for their valuable work during the year, and expressed the pleasure felt by the Council at the close collaboration which had been established with the Federation and the Research Council, as well as their appreciation of the encouragement given to research for the industry by the Department of Scientific and Industrial Research. Referring to the activities and publications of the Institute, he mentioned particularly two reports of the Research Committees and a symposium on steelmaking published last year, and stated that next year it is proposed to hold a symposium on blast-furnace practice.

Autumn Meeting

The President announced that the autumn meeting would be held at Cardiff from September 12 to 16. Visits would be paid to the works of Guest Keen Baldwins Iron and Steel Co., Guest Keen and Nettlefolds, the Ebbw Vale plant of Richard Thomas and Co., and to the works at Newport of John Lysaght, the Whitehead Iron and Steel Co., and the Newport and South Wales Tube Co.

Presentation of the Bessemer Gold Medal

The President said he had a very pleasant duty to perform—namely, to announce that the Council had decided to award the Bessemer Gold Medal for 1939 to Mr. James Henderson. The award was made to Mr. Henderson in recognition of his life-long service to the industry and in thankfulness and gratitude for the encouragement which he had given in act and by example to technical development. His career had special significance for all who were making iron and steel in the various works, and was an encouragement to them. In the forty-five years during which Mr. Henderson was in active service with the Appleby-Frodingham Steel Co. he held every position from chemist to managing director, and was now deputy chairman, a very fine record indeed. He was regarded with great affection by his staff and by his colleagues, the affection for a man who knew his job, who could be trusted, and for a strong man who had no need to parade his strength.

In acknowledging the award, Mr. Henderson gave a brief historical account of Henry Bessemer, whose researches and inventions covered the widest range of arts and manufactures, and who, in 1873, handed over to the Institute an invested sum of £400, the interest on which was to provide a gold medal which was to be given to persons who had performed some merit—worthy service to the iron and steel industry. In conclusion, Mr. Henderson thanked the Council for making the award and the President for the particularly happy way in which he had presented it.

The Dinner

Nearly a thousand members and guests attended the dinner at Grosvenor House, over which Lord Dudley presided. The chief guest at this function was Admiral of the Fleet Lord Chatfield, Minister for the Co-ordination of Defence. Proposing the toast of the Iron and Steel Institute, Lord Chatfield said that the Admiralty had had closer connection with the iron and steel industry than any other defence department. Less than ten years ago the Admiralty in one year purchased no armour at all; now they were receiving from three firms as much as was produced by five firms during the peak period of the Great War.

Another of the activities of the Institute was that of research into the corrosion of steel. The problem of corrosion in aircraft had been the subject of much investigation. If it could be overcome entirely great advantages would result from the increase of safety and the diminished need for reconditioning. In this respect the steelmakers had made a great contribution by the development of stainless steels to their present state of high performance, and considerable quantities of these steels were now incorporated in aircraft structures with highly satisfactory results.

The Government had set up an organisation which had had the most marked effect in the relationship between the supply officers of the three Services. It had enabled, during the last two or three years of big expenditure on armaments, the Admiralty to carry out its programme of rebuilding the Navy; the Air Ministry to create a vast

organisation in industry of an entirely new type, and to an extent never previously envisaged in this country, and at the same time for the War Office to build up its productive capacity to the limited extent that it has been asked to for its own forces and the anti-aircraft defence of this country. All this had been accomplished without any friction or serious clashing between the three great Departments. He thought that was a great tribute to the decision that they made twelve years ago, and had made them loth to depart from those principles and to create a Ministry of Supply. It was always recognised that a Ministry of Supply given, as it would be, special powers over industry which were denied ordinarily to the defence supply departments, had great advantage where mass production was required and where the advantages of this mass production were for the time being greater than its disadvantages.

TECHNICAL SESSIONS

In the technical sessions held considerable attention was given to the reports, which are briefly reviewed in this issue, and from which much discussion arose. A large number of papers on a variety of subjects were also presented, only in a few cases, however, was there time for discussion ; some of these papers are here summarised.

The Refining of Metal in the Basic Open-Hearth Furnace

WHETHER the hot-metal process or the scrap process is used, the refining of the metal in the basic open-hearth process consists in the removal of some of the carbon and the partial elimination of sulphur and phosphorus, the manganese changes which occur being incidental to the process. In this paper by Mr. W. B. Lawrie, attention is directed more particularly to the removal of sulphur. This element depends for its removal on the presence of lime, manganese, manganese oxides, and sometimes fluorspar in the slag, and the reactions involved are influenced by the thermal, chemical and mineralogical conditions of the slag. Superimposed on these is the effect of the gas, which will contain varying amounts of sulphur ; and whilst the gas may decrease the sulphur content of the steel it is more than probable that any actual decrease in sulphur is only to be effected in practice by balanced reactions involving the bath and slag. The present paper is an attempt to view the process when fluorspar is used, in the light of Colclough's conclusions.[1]

The addition of fluorspar to the basic open-hearth furnace to facilitate the removal of sulphur was suggested by Saniter. Its influence is probably indirect, the fluorspar giving greater fluidity to the slag and enabling it to carry additional lime. In the actual sulphur removal the manganese probably plays practically a catalytic part, undergoing a cycle of reactions in suitable slag conditions. Apart from the sulphur removal, however, the manganese passes from the metal to the slag, or from the slag to the metal, the direction of migration depending on the slag conditions.

When the bases are exceptionally low, and the available MnO is needed to give a monosilicate in the slag, there is probably no reduction of the manganese to the metal. When the slag is about "neutral" and forms a monosilicate without the MnO, then the latter is probably free to be reduced on the addition of lime :—

$$(2MnO)SiO_2 + 2CaO \longrightarrow (2CaO)SiO_2 + MnO,$$
$$MnO + C \longrightarrow CO + Mn.$$

If the bases are definitely in excess, as when fluorspar and lime are added, then no reduction of the MnO of the slag is possible. This may be due to the formation of a higher acidic oxide of manganese, which then readily reacts with the bases of the slag to give calcium manganite, $CaO.MnO_2$. This latter seems to be a stable compound from which manganese cannot subsequently be reduced.

This view would appear to receive support from the fact that the presence of oxides inhibits the reduction of manganese oxide from the slag. With a large feed of scale or ore, there will be no increase of the bath manganese, whatever the lime content of the slag. Presumably the oxide present promotes the formation of such higher acidic oxides of manganese as will readily pass to the basic slag by the formation of calcium manganite.

It has been noticed that chromium behaves in a very similar way to manganese, which seems to confirm further the view, as chromium, like manganese, can give higher oxides which are acidic in character. Presumably the chromium is returned to the slag as an acid oxide which gives calcium chromite with the bases of the slag. Nickel is unchanged in the furnace, as its heat of formation prevents any such oxidation.

The view would seem to obtain further support from the fact that phosphorus is also removed from the metal by the formation of an acidic oxide, which then reacts with the basic slag. Incidentally, the presence of fluorspar renders the slag useless as a fertiliser, because the phosphates are insoluble in the weak soil acids. It has been suggested that this is due to the formation of a fluor-apatite, $CaF_2.3\,CaO.P_2O_5$.

Carbon is removed best by a slag of low basicity ; consequently, the use of fluorspar is undesirable where large quantities of carbon have to be eliminated. The suggestion that manganese and chromium, like phosphorus, migrate to the slag on account of the formation of higher acidic oxides in the presence of oxidising conditions seems to be in complete agreement with the behaviour of iron oxides. Only when the reducing conditions set up by the presence of carbon in the early stages have been largely removed is there an appreciable increase of the oxide in the slag, this increase being due to the oxidation of the FeO to Fe_2O_3, which then acts as an acidic oxide to give calcium ferrites.

A Study of "Strain-Age-Hardening" of Mild Steel

THERE are two clearly defined kinds of age-hardening of mild steel : one known as "quench-age-hardening" and the other as strain-age-hardening. In each instance the hardening will take place at ordinary atmospheric temperature, but the rate at which it develops can be accelerated by heating the specimens to low temperatures. The procedure involved in the production of these two kinds of age-hardening are different, but many workers have sought to correlate the two sets of phenomena. In the investigation described in this paper by Dr. C. A. Edwards, Mr. H. N. Jones and Mr. B. Walters, however, the authors have confined their studies to strain-age-hardening.

The study concerns the influence of cold-work produced by tensile strains, with particular reference to the influence of small degrees of strain followed by ageing at 250° C. In most instances, the amount of strain to which the specimens were submitted before ageing was determined by the character of the material itself. The procedure was to increase the tensile stress slowly to the yield-point, and then allow ample time to permit the strain to be completed while the stress was maintained at a constant value. After ageing, the specimens were tested for the usual tensile properties. Within these limits of straining and ageing at 250° C., no evidence has been obtained which leads to the conclusion that oxygen plays any part in strain-age-hardening, so far as this quality is revealed by a rise in the yield-point or ultimate-stress values. A special sample of steel, containing as much as 0·48% of potentially active aluminium, and therefore presumably containing no active oxygen, displayed the same quantitative tendency to strain-age-harden as all the other samples that have been examined in the present investigation.

So far as can be gauged at present, these observations are true for more extensive tensile strains than are referred to above, but the number of experimental results obtained in this connection do not cover such a wide range. The general conclusions which the authors have formulated from the present work are summarised as follows :—

[1]Colclough. *Jour. I.S.I.* 1923, 1, pp. 267–286.

(1) The yield-point in tension of normalised mild-steel specimens, up to a value of about 14 tons per sq. in., appears to be proportional to the number of ferrite crystals per linear millimeter. This is not the case when the yield point is above 14 tons per sq. in. It is not at present known whether this deviation is really due to a diminution in the crystal size, is an indirect result of a difference in the constitution of the ferrite, or is due to some other difference in the structure resulting from the rapid rates of cooling which were adopted to produce the small crystals.

(2) The amount of strain that occurs at the yield-point is closely related to the stress at which the yield takes place. The following is an approximate expression of this relationship :

$$\text{Yield stress} = 3{\cdot}5\ (\text{percentage strain} + 1).$$

(3) The increase in the yield-point stress after straining at the yield and ageing at 250° C. can be indicated as follows :—

(Yield-point in normalised specimen) $\times$ 1·4 = Yield-point after ageing.

or

$$\text{Yield-point after ageing} = 4{\cdot}6 + 5{\cdot}4\ (\text{percentage strain}).$$

(4) The ultimate stress after straining at the yield and ageing at 250° C. can be expressed thus :—

$$\text{Aged ultimate stress} = 1{\cdot}05\ (\text{initial yield-point}) + 10{\cdot}3,$$

or

$$\text{Aged ultimate stress} = (1{\cdot}19 \times \text{initial ultimate stress}) - 2{\cdot}66.$$

The Strain-Ageing of Dead-Mild Steel Strip used in the Pressing of Automobile Bodies and Accessories

THE investigation described in this paper by Dr. J. W. Rodgers and Mr. H. A. Wainwright is concerned chiefly with the phenomenon of strain-ageing in so far as it affects the rolling and pressing of steel strip for automobile body parts and accessories. The chief difficulty encountered by the industry with respect to strip is the variation in "drawability" after the various preliminary mechanical treatments. These treatments involve the cold deformation of the metal usually to a small degree.

Five dead-mild steels have been tested, and the influence of strain-ageing upon their tensile and penetration hardness properties investigated. The results show that though the effect of ageing upon the hardness is a simple increase, which other workers have noted, the tensile results, particularly those of percentage elongation, do not follow the simple changes in hardness which take place. There is considerable evidence for the phenomenon of preliminary recovery, a change which takes place in the direction opposite to that usually associated with ageing, prior to the major ageing changes.

There appears to be a fundamental difference between hardness and elongation, these properties not exhibiting the degree of complementary relationship usually associated with them. Small fundamental differences are also observed between hardness and maximum strength. Normalising appears to increase the rate of strain-hardening and also produces a more erratic material than does annealing. The results of a few experiments on the ageing of sub-critically quenched steel which had been subjected to cold-work are quoted. The authors do not discuss the fundamental causes of strain-ageing. They do not think that their experimental results entitle them to do so.

Some Applications of Spectrograph to the Quantitative Analysis of Ferrous and Non-Ferrous Metals

APART from a reference to the origin of spectroscopy, the scope of this paper by Mr. F. G. Barker is confined to a description of the modern spectrograph, to a review of the work done in the Admiralty Laboratory, Sheffield, in connection with spectrochemical methods for the quantitative analysis of ferrous and non-ferrous metals and alloys, and finally to a summary of the elements which are now being estimated as a routine in various alloys, the percentages covered, and the accuracy obtained. The technique employed for the preparation of arc spectrogram for the estimation of impurities and minor constituents is described, also the methods of preparation and use of standard tables for the evaluation of spectrograms by the internal comparison method.

Experiments which were made to extend the scope of spectrochemical methods to cover the estimation of many of the constituents of alloy steels show that by employing spark spectrograms, and photo-electric methods for their evaluation, it is possible to make quantitative determinations of several elements with an accuracy closely approaching that obtainable by chemical analysis. Standard tables and graphs which are used for the evaluation of spectrograms and the range of steels to which they are applicable are shown. The technique adopted is fully described, and the effect of variations from the conditions which have been standardised is given. The latter covers variations in time of exposure, period and temperature of development, use of old developer, the physical condition of the sample and the shape of the electrodes. The effect of heterogeneity in the sample under examination and steps being taken to obtain reliable results for "average composition" are described. It is also shown how spectrographic methods can be conveniently applied to the analysis of segregates. Examples are given to show the large saving in time effected by the use of spectrographic methods for the analysis of certain materials.

Some Applications of the Durville Rotary Process to the Casting of Steel

DEVELOPMENT work carried out at Woolwich[1] showed an important advantage of the Durville process is its ability to fill the mould with metal at a low superheat, thus ensuring a reduction in ingot porosity and crystal size. The use of such low temperatures in the normal methods of casting would lead to unsoundness in the ingot due to entrapped air and to the freezing-up of the metal near the nozzle and stopper in the travelling ladle. Exploratory work on the application of the Durville process to the casting of small steel ingots has now been carried out, and the results obtained are described in this paper by Dr. L. Northcott.

It is shown that this process, originally devised for the non-turbulent casting of ingots of non-ferrous alloys containing aluminium, can be applied with advantage to the casting of small steel ingots. The ability to cast at a sufficiently low superheat ensures that the crystal structure is wholly small and equi-axial, thus reducing segregation and "ingotism." There is also slight improvement in the surface quality and mechanical properties as compared with steel cast by ordinary methods.

The author considers that the most important application of the Durville process to steel would be in the casting of the smaller types of ingots of high-quality alloy or tool steels, where freedom from segregation and coarse crystal structure, and perhaps also a superior surface quality, are required. The process is unlikely to be of use in the manufacture of large ingots of the lower-quality steels, if only on account of the practical difficulties involved.

The Rolling of Sections at the Appleby-Frodingham Steel Co., Ltd.

A MODERN and up-to-date mill, which is sufficiently flexible to cater for the very varied demand for shapes met with in Great Britain is discussed, and a brief description of the plant given in this paper by Mr. W. T. Wilson, together with some of the methods used in the never-ending quest for improvements in practice, with consequent reduction in cost. The layout of the mill is

1 Summarised in "The Casting of Brass Ingots," by Genders and Bailey, Chapter 14. London, 1934: The British Non-Ferrous Metals Research Association (Research Monograph No. 3).

illustrated, and also the design of the cogging rolls and the standard ingot used. An improved method of using the soakers is mentioned.

Three examples of roll design for 10 in. × 3½ in. channels are illustrated and discussed, the actual rolling rate per hour and yield from each design being given. Two designs for 15 in. × 5 in. joists are dealt with in the same manner. Four layouts for joists of various sizes are illustrated, and their respective merits are explained and criticised, the yield and rates per hour being given. The diagonal system of rolling is dealt with, and yields and rolling rates are given to support the points made.

The savings made by using the new-type alloy rolls on various sections are shown, and comparative tonnages per inch of roll life are given. The method of reducing roll changing to a minimum is described and changing times are quoted.

The new mechanical cooling bank and roller-straightening machines are described, and results from the latter for various groups of sections are tabulated. In connection with the 15-in. mill, a four-roll design is illustrated, the method of rolling is described, and the savings are enumerated.

The mills consist, briefly, of a 36-in. cogging mill (two-high), a 32-in. finishing mill (three stands, two-high), and a 15-in. merchant mill (four stands, three-high).

The Influence of Carbonising Conditions on Coke Properties

PART II.—THE EFFECT OF PRESSURE, TEMPERATURE, RATE OF HEATING AND "SOAKING" ON COKE STRENGTH.

A QUANTITATIVE study of the effect of the carbonising conditions upon the properties of coke has been made by methods similar to those described in Part I[1] of this research. The results, given in the present paper by Mr. H. E. Blayden, Mr. W. Noble, and Professor H. L. Riley, indicate that relatively small pressures up to approximately 40 lb. per sq. in. applied during carbonisation bring about great increases in the strengths of cokes prepared from weakly coking coals. Further increases in pressure up to 500 lb. per sq. in. have little or no effect upon the coke strength. The development of coke strength during carbonisation has been found to occur in two distinct temperature ranges. In the first, 400°–550° C., which coincides with the plastic range, the coke strength is greatly affected by the pressure applied during carbonisation. The second temperature range is from 650° C. upwards, when the strength developed depends only on the maximum temperature reached during carbonisation and is independent of the pressure (up to 500 lb. per sq. in.) applied during carbonisation. Variations in the rate of carbonisation and time of soaking bring about only small differences in strength.

Although these results have been obtained using poorly coking coals, they appear to throw considerable light upon the fundamental factors of coking in general. They make clear the very important role played by relatively small pressures developed in the coking mass as it passes through the plastic condition. It is not unlikely that gas evolution, bubble formation and surface tension are responsible for the development of pressures of the order of 10–40 lb. per sq. in. in the plastic mass. Whereas with the poorly coking coals employed, a variation in the carbonising rate had little effect upon the strength of the resulting coke, presumably because the constant applied external pressure had a predominating influence, with a good coking coal which develops pronounced plasticity during carbonisation, a variation in the rate of heating would cause considerable variations in the pressures developed naturally in the plastic mass, with a consequent effect upon the properties of the resultant coke.

The increase in strength which occurs in the second temperature range begins at that temperature at which the coke becomes an electrical conductor. This is of fundamental significance, for it indicates that at approximately 650° C. new cohesive forces come into play, owing to the liberation of metallic electrons. These new forces are probably also responsible for the contraction and consequent fissuring which occurs as the carbonisation temperature increases above 650° C.

1 *Jour. of I.S.I.* 1937, No. II, p. 47.

Nickel-Iron-Aluminium Permanent-Magnet Alloys

FOLLOWING preliminary work mainly on samples of nickel-iron-aluminium alloys cast in chill moulds of cast iron, it was decided to explore fully the most favourable regions of composition for magnets, varying the nickel content between 23 and 29% and the aluminium content between 8 and 17%. The investigation of the properties of the alloys was conducted under three headings: Determination of the critical quenching temperature—i.e., the temperature above which it is necessary to heat a magnet before quenching; determination of the optimum cooling rate in the quench; and investigation of the effect of tempering and the determination of the maximum magnetic properties.

In addition to the simple ternary alloys, alloys with additions of carbon and of copper were investigated, and also cobalt containing alloys of the "Alnico" type. The variations of the magnetic properties of the optimum heat-treatment with the compositions are given in a series of diagrams in this paper by Dr. Walter Betteridge. It is shown that the presence of carbon is very deleterious. The addition of approximately 5% of copper improves the remanence—an increase of approximately 7% being obtained. Magnets of nickel-iron-aluminium-cobalt alloy with or without copper have somewhat better properties than the simpler nickel-aluminium alloys. Some 63 different alloys were prepared with compositions in the following ranges: Nickel, 16–26%; cobalt, 4·5–16·5%; aluminium, 7–13%; copper, 5%; remainder, iron. It was found that these alloys needed to be quenched from a much higher temperature to preserve single-phase structure, and hence to obtain good magnetic properties, than the cobalt-free alloys.

Finally, the author gives an account of several investigations into the cause of the high coercivity of the alloys by X-ray diffraction methods.

Ten Years' Development in Steam Engineering at the Port Kembla Steelworks, N.S.W., Australia

PRODUCTION activity at the Port Kembla Steelworks commenced in 1928, with the blowing-in of its first blast-furnace. During a decade of growth many new units have been added. The works now include by-product coke-ovens, two blast-furnaces with a combined daily capacity of 1,850 tons of iron, five open-hearth furnaces with a yearly ingot capacity of nearly half a million tons, soaking pits, an electric blooming mill, rail and structural mill, continuous billet and sheet-bar mill, and a merchant mill, and a plant for making centrifugally-cast pipes. In this paper by Mr. H. Escher attention is directed more particularly to the developments in steam engineering that have taken place at these works since the plant was put into operation.

Two phases of steam engineering are considered separately. In the first, dealing with steam generation, the author describes early difficulties, the first boiler-house extension, the introduction of pulverised fuel, and the conversion of the gas-fired boiler plant to use this material, the blast-furnace gas supply, combustion chamber design, baffling and superheater location, the mechanical draught plant, combustion control and the instruments used, and the burning of coke breeze. In the second part, dealing with steam utilisation, the general distribution of the steam and its use in the blast-furnace plant, electric generators, open-hearth plant, rolling mills and by-product coke-ovens are discussed.

The Effect of Nitrogen Additions and Heat-Treatment on the Properties of High-Chromium Steels

THIS paper, by Mr. E. W. Colbeck and R. P. Garner, records the results of an investigation into the manufacture, and the effect of heat-treatment on the properties of high-chromium steels containing varying amounts of nitrogen. Experiments are described which were designed to covercome the normal brittleness and coarse grain size of high-chromium steels. A technique has been developed for alloying nitrogen with chromium steels containing between 21 and 28% of chromium. The preparation of a nitrogen-rich " temper " alloy of iron and chromium and the subsequent manufacture of ingots of high-chromium steel from this material are described in detail.

It has been found that the optimum nitrogen content of these steels is of the order of one-hundredth of their chromium content ; if such an amount is exceeded there is a marked tendency for the ingots to become unsound and gassy, owing to the release of nitrogen on solidification.

The heat-treatment of these nitrogen-bearing high-chromium steels has been studied. It has been found that improved toughness and ductility can be obtained by quenching steels containing between 22·5 and 28% of chromium from between 1,100° and 1,200° C., provided that nitrogen is present. A further marked improvement is obtained by adding $\frac{1}{2}$–1$\frac{1}{2}$% of nickel to such steels. The heat-treatment recommended by American workers in this field does not produce the desired toughness and ductility.

The microstructures of a large number of alloys have been examined after different heat-treatments. This has shown that a duplex $\alpha + \gamma$ field exists at high temperatures in the Fe–Cr–C–N_2 system. Quenching from this phase field results in the retention of a plain ferrite-plus-austenite structure after treatment ; this structure coincides with the best toughness and ductility in these steels. It has been confirmed that additions of nitrogen to these high-chromium steels have a marked refining action on their grain size.

Experiments have been carried out on the heat-resisting properties of 23–28% chromium steels, and it has been found that nitrogen additions are valuable in inhibiting grain growth at 1,100° C. and in preventing embrittlement after exposure to such conditions. During the course of the investigation it was repeatedly observed that additions of nitrogen followed by the correct heat-treatment improved the machinability of these high-chromium steels.

A Note on the Slow Cooling of Ingots

IT is necessary at times to allow hot steel bars or ingots to cool slowly and uniformly, and for this purpose they are immersed in a bed of a dry material of low thermal conductivity. At some steelworks, diatomaceous earth (kieselguhr) has been used for this purpose because of its exceptionally low thermal conductivity, but as all these diatomaceous earths contain a high proportion of free silica in a very fine state of division, the dust which is formed in handling them is dangerous to health.

At the suggestion of H.M. Medical Inspector of Factories, a series of tests have been carried out to ascertain the possibility of substituting an innocuous material for the undesirable diatomaceous earth, and a number of materials have been tested and compared with the diatomaceous earth which had been in use in one steelworks. The results given in this note by Mr. W. J. Rees indicate that the efficiency of the light magnesia is equal to that of diatomaceous earth, and that the commercial magnesia and crushed limestone are only slightly less efficient.

The Interpretation of Thermal Curves and Some Applications to Ferrous Alloys

FOR a theoretical study of the qualitative and quantitative interpretation of thermal curves, it was first assumed that the heat-content/temperature curve was known. In the work discussed in this paper by Mr. T. F. Russell, two methods of cooling are considered : Cooling in constant-temperature surroundings—e.g., in air, liquids, salt baths, etc. ; and cooling in a space which is cooling linearly with time—e.g., cooling in a tube furnace, which is itself cooling so slowly that, over fairly wide ranges of temperature, the cooling of the inner wall of the tube is approximately linear ; and the following types of phase changes : Change at constant temperature ; change over a range of temperature ; and a combination of these two—e.g., a hypo-eutectoid change.

It is shown that a " peak " on an inverse-rate curve may be due to either an abrupt increase in specific heat or an evolution of heat at constant temperature. In the first case the relative size of the peak is independent of the rate of cooling ; in the latter case the relative size of the peak varies appreciably with the rate of cooling, becoming smaller as the rate of cooling becomes slower. A *decrease* in specific heat gives a peak in the opposite direction, but in practical curves this may be mistaken for a peak indicating an *increase* in specific heat. The theoretical deductions are then applied to a number of inverse-rate curves obtained on a nickel-chromium steel.

Some theoretical heat-content/temperature curves for iron-carbon alloys have been drawn, using the best available numerical values of the heat evolved during the $\gamma \rightarrow \alpha$ change and the $\gamma \rightarrow \alpha + Fe_3C$ eutectoid change.

Slag Inclusions and Acid Open-Hearth Refining of High-Carbon Steel

AN arbitrary scale for slag rating and heat diagrams kept during the melting and refining of acid open-hearth steel at S. K. F. Hofors, Sweden, from the early part of 1927 have been used in statistical analyses to study the possible influence of various operating factors on the resultant slag inclusions in the steel, the results of which are given in this paper by Dr. Haakon Styri. No obvious correlation was found between any single operating factor up to the point of the final additions of deoxidisers and the observed oxidic slag inclusions. Even the rate of carbon elimination towards the end of refining, which might be expected to be of importance according to prevalent theories of the rate of reaction, seemed to be of only small importance. A great number of experimental heats were run with drastic changes of procedure, particularly with respect to the rate of carbon elimination, and again no correlation could be found. The rates were controlled by the manipulation of the gas and air mixture, regulation of the draft and additions to the bath. Evidently the rate of carbon elimination is determined by the rate of diffusion of oxygen to the bath and is explained by a high value of the velocity constant for the reaction $FeO + C \longrightarrow Fe + CO$.

Note on Discontinuities in the Resistance-Temperature Curves of Commercially Pure Iron and Steel

SOME previous investigations into the possibility of changes in iron and steel occurring in the temperature interval from 50° to 450° C. are discussed in this paper by Dr. C. Sykes and Dr. F. W. Jones, and further measurements made of the variation of the temperature coefficient of electrical resistance as a function of temperature. The results show that the discontinuities in the temperature coefficient over temperature intervals of 3° C. are of the same order as the experimental error—i.e., ± 2%.

The results confirm the work of Burgess and Kellberg, and show that the changes in temperature coefficient of the present authors' samples over temperature intervals of the same magnitude as those chosen by Thompson are quite small—i.e., at least five times smaller than those recorded by Thompson. The authors consider that the results of the present preliminary experiments indicate the difficulty of eliminating spurious effects, and think it probable that residual discontinuities obtained with the final apparatus are also spurious and could be eliminated with improved technique.

Eighth Report on the Heterogeneity of Steel Ingots

THIS report, which was presented at the recent annual meeting of the Iron and Steel Institute, is the eighth published by the Committee since its inception, and marks the position reached after nearly fifteen years' intensive study of steelmaking problems. The early work of this Committee, which is a Joint Committee of the Iron and Steel Institute and the British Iron and Steel Federation, consisted mainly in disclosing the degree of heterogeneity which did in fact exist in steel ingots of different types, cast under different conditions. A general measure of success was also achieved in determining the major factors which govern the magnitude and location of segregates, and as a result there is little doubt that the general quality of steel ingots has improved. During recent years, however, it has become increasingly apparent that there was a limit to the results which could be achieved by the control of casting conditions and mould design alone, and that ultimate progress of a fundamental character was intimately bound up with a careful study of the reactions proceeding within the steel itself, in the furnace, in the ladle, and in the mould.

In this sphere achievement was handicapped by inability accurately to measure the temperature and oxygen content of the steel. The Committee, therefore, put in hand, at the National Physical Laboratory, at Sheffield University, and elsewhere, work concerning the accurate determination of temperature and oxygen content, the results of which are given in this report.

Segregation of Steel

In previous reports of the Committee on the subject of heterogeneity of steel ingots, the view has been expressed by certain investigators that segregation might occur in the molten state and experiments carried out at Sheffield University, described in this report, give evidence in support of this hypothesis. In the previous experiments steel containing a high content of impurities was kept molten in a small crucible for 24 hours, and considerable segregation of all impurities in the head was found on cooling. Criticism was levelled against these experiments on account of the unusually high content of impurities, and the small size of the ingot. In the present contribution results are submitted on a somewhat larger mass of more normal composition, and evidence in support of the formation in the liquid steel of an insoluble complex rich in sulphur and phosphorus is put forward.

Oxygen Determinations of Bath Samples from Acid Steel

Another section consists of a detailed account of oxygen determinations on a series of bath samples from a heat of acid open-hearth steel. Seventeen samples were taken over a period of 6½ hours and were submitted to vacuum fusion and iodine extraction, the iodine residues being subsequently analysed by micro-analytical methods. The change in composition of the inclusions during the progress of the heat, as well as the variation in the oxygen content of the samples as determined by vacuum extraction, are plotted against the corresponding analyses of the slag and metal. The whole investigation provides a very full picture of the changes which take place in the slag and metal during the working of a typical Siemens-Martin heat, and is worthy of careful study by students of steelmaking.

The Delta Region in Carbon Steel

A brief note is given in one section dealing with the delta region in carbon steel. It shows how scanty are the data concerning this phase, yet the subject is of importance when considering, from a theoretical standpoint, the changes in low carbon steel when passing from the liquid to the solid state. The experimental difficulties of determining liquidus, solidus, and especially solid-solubility curves at the high temperatures involved have deterred most investigators from attempting the task.

A Nickel-Chromium-Molybdenum-Vanadium Steel Ingot

Some indication of the high degree of homogeneity now obtainable in ingots made under modern production conditions is obtained on reference to a section which gives the results of a study of a nickel-chromium-molybdenum-vanadium steel ingot. The ingot is one of a 32½-ton cast of 47 ingots produced for the Air Ministry Research Committee. Four ingots, representing the beginning, the middle, and the end of the cast, were examined, and the present contribution consists of a detailed study of the forty-fifth ingot. The main point of interest in this investigation is that an ingot is disclosed which demonstrates the high degree of homogeneity obtainable in small ingots.

Pyrometry

In the Committee's last report a preliminary account was given of the direct-immersion thermocouple developed by Dr. Schofield at the National Physical Laboratory. In the present report, a contribution by the Liquid Steel Temperature Sub-Committee is devoted largely to an account of further developments of this instrument and to a critical account of its use in practice for measuring the temperature of liquid steel in the furnace, launder, ladle, trough or mould. Constructional details are set out, possible sources of error are discussed, and typical results obtained in various steelworks are given. The thermocouple as now described in this section may be considered a practical instrument for general steelworks application.

Second Report of the Ingot Moulds Sub-Committee

The second report of the Ingot Moulds Sub-Committee constitutes another section. It deals with premature failure of the mould wall by major cracking as distinct from cracks on the working face, and includes a study of the phenomenon itself, its various causes, suggestions concerning the character of the stresses set up in the mould wall when casting, and a study of appropriate methods for determining liability to cracking. The report also embraces the more fundamental aspects of the work. In this connection an important experiment on the determination of the temperature gradients in the mould is described, and a preliminary examination of the results is made.

Some notes are given on the effect of the silicon content and preferential cooling on the service behaviour of ingot moulds. A distinction is made between relatively large ingot moulds for forged steel products and small moulds for high-production plants, the conditions of manufacture and use in the two cases being dissimilar.

Report of Inclusions Count Sub-Committee

From time to time, most people concerned with the examination of steel have felt the need for a quantitative system for the determination of non-metallic inclusions in steel, and the Fox inclusion count method has been described in METALLURGIA.* Various reports published by the Committee have developed, in successive stages, chemical methods for determining the content of non-metallic inclusions in steel; the formation of the Inclusions Count Sub-Committee was, however, brought into being in order that a systematic study might be made of the quantitative microscopic methods for evaluating the "cleanness" of steel, and a report of this Sub-Committee constitutes the concluding section in this report.

Tests to ascertain the reproducibility of results from different methods by different observers have shown considerable differences in the counts obtained on each sample of steel tested. The Sub-Committee conclude that these quantitative attempts to determine the inclusion content of steel are invaluable to steelmakers for purposes of process control; such methods, however, even in the hands of experts, do not yield results sufficiently in agreement for inclusion counts to be incorporated in specifications or adopted for reception purposes.

* July, 1935, pp. 83–4.

Business Notes and News

Iron and Steel Industry Increase Output

The British Iron and Steel Federation reports that there were 100 blast-furnaces in operation at the end of April in the United Kingdom, an increase of five as compared with the end of March. The production of pig iron in April was 608,900 tons; in the preceding month the output was 603,600 tons, and that of April last year, 661,000 tons. The output last month included 103,500 tons of hematite, 392,600 tons of basic, 92,000 tons of foundry, and 12,000 tons of forge pig iron.

Steel production continued to expand in April, since, although the total output is less than in the preceding month the number of working days was reduced by three. The output of steel ingots and castings was 1,058,200 tons, compared with 1,170,000 tons in March and 938,600 tons in April, 1938. Allowing for the reduced working days, the average daily output during the month shows an increase over March. The number of open-hearth furnaces in operation during the month increased by six to 326, and further facilities for increasing output are available with increasing demand.

Shipbuilding Orders

The response to the Government's proposals to assist shipping and shipbuilding has been of an enthusiastic nature, and as far as shipbuilding is concerned so many orders have been placed since the proposals were made that they easily exceed the total placed for the whole of last year. It is probable that many shipowners held up development schemes in the hope that some action would be taken by the Government, and immediately took advantage of the facilities presented in order to be within the time limit given, with the result that from a condition of grave depression the position of the shipbuilding industry has been changed into a boom period in a relatively short time.

It is understood that orders for nearly 900,000 tons of shipping have been placed since information regarding the subsidy was published at the end of March. This sudden surfeit of orders raises many problems. They have come at a time when the demand for steel for other purposes has been gradually rising, and when the shipyards are operating with depleted staffs. For some time the industry has been in the throes of a depression and many skilled workpeople have taken up other work. It is probable, therefore, that though the orders have been placed, the question of delivery will depend upon so many factors outside the control of the shipbuilder. As far as the industry is concerned, it would have been better to adjust the Government plans so that the orders could have been spread over a longer period, but these orders may be regarded as an integral part of the country's armament programme, in which case preference will be given in obtaining supplies of materials.

Tinplate Merger

The amalgamation of several Welsh tinplate companies is announced. The name of the new concern is Llanelly Associated Tinplate Companies, Ltd., with head offices at Llanelly. Five companies are involved—Old Castle Iron and Tinplate, Llanelly; Western Tinplate, Llanelly; Ashburnham Tinplate, Barry Port, Carmarthen; Kidwelly Tinplate, Kidwelly, Carmarthen; and Teilo Tinplate, Pontardulais, Glamorgan.

The amalgamation was decided upon to meet the changed circumstances in the Welsh tinplate industry brought about by the competition of the Ebbw Vale Strip Mills of Richard Thomas and Co., Ltd. It is the forerunner of the establishment of a similar plant at Llanelly. Sir Evan Williams, chairman of the Coalowners' Association of Great Britain, is chairman of the directors of the new group.

THE PROPRIETORS of the BRITISH PATENTS Nos. 465345 and 465346 for "Process for the refining of lead and lead alloys" are prepared to enter into negotiations for the SALE of the patent or for the grant of licences thereunder. Any inquiries to be addressed to Carpmaels & Ransford, 24, Southampton Buildings, London, W.C. 2.

A new large ingot mould for English Steel Corporation

World's Heaviest Ingot Mould

For very many years English Steel Corporation Ltd., Sheffield, claimed the record for Britain's largest steel ingot, and towards the end of 1937 they lifted this record to 230 tons. The development in the size of steel ingots is largely due to the synthetic production of chemicals and the hydrogenation of coal to produce petrol and oil, an entirely new and rapidly growing industry, which necessitated the manufacture of large hollow forged high-pressure vessels. The grid scheme, which has been developed in this country, also called for enormous forged boiler drums and steam receivers, and in the marine world large liners and aircraft carriers being built also call for very heavy forgings.

English Steel Corporation, who specialise in the manufacture of these forgings, have a heavy programme before them in this class of work and are regularly producing ingots of record size in both carbon and alloy steels.

What is claimed to be the world's heaviest one-piece ingot mould has just been delivered to their Vickers Works, Sheffield. The production of a casting of this size and strength is an outstanding achievement in iron foundry work; 170 tons of molten metal were required and seven ladles which were used took only 8¾ minutes to pour. The casting was produced by the Brightside Foundry and Engineering Co. Ltd.

Scrap Conservation

Some time ago we discussed the importance of adequate supplies of scrap iron to the steel industry. The economic advantages of a plentiful supply are not always appreciated, and yet the steel industry is finding it difficult to obtain its requirements. Measures are now being taken to meet this position, which will be based on the retention of all home supplies. Steel firms are being encouraged to return to the normal scrap-pig iron proportion in an effort to conserve supplies. Efforts to supplement home supplies—by imports from abroad—are not too successful, although it is understood that substantial tonnages have been purchased in the United States for shipment to this country. Some firms seem to regard the fixed prices for scrap as a retarding influence, believing that the current price is relatively low. It is likely that a higher price would encourage freer movement of scrap iron, not so much of home supplies as of imports.

Since the agreement formulated between steelmakers and scrap merchants, towards the end of February, 1937, exports of scrap iron from this country have been reduced, though for a time last year merchants sought a relaxation of this embargo because they found a difficulty in getting rid of their stocks. The position is somewhat different now, and steelmakers are not getting as much as they can use.

Index on Spectrographic Analysis

In our last issue reference was made to an index of the literature on spectrographic issued by the American Society for Testing Materials; we are advised that copies of this book can be obtained from Adam Hilger, Ltd., 98, St. Pancras Way, Camden Road, London, N.W. 1.

MARKET PRICES

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ANTIMONY.

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Crude	39	0	0

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Brazed Tubes	,,	0	1	1½
Rods Drawn	,,	0	0	9½
Wire	,,	0	0	8½
*Extruded Brass Bars	,,	0	0	4¾

COPPER.

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Electrolytic	47	15	0
Best Selected	47	10	0
Tough	48	0	0
Sheets	78	0	0
Wire Bars	48	15	0
Ingot Bars	48	15	0

Solid Drawn Tubes	lb.	0	1	0¾
Brazed Tubes	,,	0	1	0¾

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Ferro Molybdenum °	,,	0	4	10
Ferro Chrome, 60-70% Chr. Basis 60% Chr. 2-ton lots or up.				
NOMINAL 2–4% Carbon, scale 12/– per unit	ton	34	15	0
NOMINAL 4–6% Carbon, scale 8/– per unit	,,	24	5	0
NOMINAL 6–8 Carbon, scale 7/6 per unit	,,	23	15	0
NOMINAL 8–10% Carbon, scale 7/6 per unit	,,	23	15	0
§Ferro Chrome, Specially Refined, broken in small pieces for Crucible Steelwork. Quantities of 1 ton or over. Basis 60% Ch. Guar. max. 2% Carbon, scale 12/6 per unit	,,	37	0	0
Guar. max. 1% Carbon, scale 13/– per unit	,,	39	0	0
§Guar. max. 0.5% Carbon, scale 13/– per unit	,,	49	0	0
‡Manganese Metal 97–98% Mn	lb.	0	1	3
‡Metallic Chromium	,,	0	2	6
§Ferro-Vanadium 25–50%	,,	0	14	0
§Spiegel, 18–20%	ton	11	0	0
Ferro Silicon—				
Basis 10%, scale 3/– per unit nominal	ton	10	5	0
20/30% basis 25%, scale 3/6 per unit	,,	12	0	0
45/50% basis 45%, scale 5/– per unit	,,	12	10	0
70/80% basis 75%, scale 7/– per unit	,,	17	0	0
90/95% basis 90%, scale 10/– per unit	,,	30	0	0
§Silico Manganese 65/75% Mn, basis 65% Mn	,,	15	15	0
§Ferro-Carbon Titanium, 15/18% Ti	lb.	0	0	4½
Ferro Phosphorus, 20–25%	ton	22	0	0
§Ferro-Molybdenum, Molyte	lb.	0	4	9
§Calcium Molybdate	,,	0	4	7

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S. Wales	£1 18	0/£2	1 6
Scotland	£1 10	0/£1	15 0
Durham	—	1	14 6
Furnace Coke—			
Scotland	£1 5	0/£1	7 6
S. Wales	—	1	7 6
Durham	—	1	4 2

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*Admiralty Gunmetal Ingots (88 : 10 : 2)		£67	0	0
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*Gunmetal Bars, Tank brand, 1 in. dia. and upwards	lb.	0	0	11
*Cored Bars	,,	0	1	1

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N.E. Coast—			
Rivets	—		
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Crown Bars	12	5	0
Lancashire—			
Crown Bars	12	5	0
Hoops	13	12	6
Midlands—			
Crown Bars	12	5	0
Marked Bars	15	5	0
Unmarked Bars	—		
Nut and Bolt Bars	11	0	0
Gas Strip	13	12	6
S. Yorks.—			
Best Bars	12	5	0
Hoops	13	12	6

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†Sheet to 10 W.G.	,,	0	1	0
†Wire	,,	0	1	1¾
†Rods	,,	0	1	1¼
†Tubes	,,	0	1	6¾
†Castings	,,	0	1	3

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Foundry No. 1	6	0	6
,, No. 3	5	18	0
N.E. Coast—			
Hæmatite No. 1	6	0	0
Foundry No. 1	5	2	0
,, No. 3	4	19	0
,, No. 4	4	18	0
Silicon Iron	—		
Forge	4	18	0
Midlands—			
N. Staffs. Forge No. 4	4	18	0
,, Foundry No. 3	5	1	0
Northants—			
Foundry No. 1	5	1	6
Forge No. 4	4	17	6
Foundry No. 3	4	18	6
Derbyshire Forge	4	18	0
,, Foundry No. 1	5	4	0
,, Foundry No. 3	5	1	0
West Coast Hæmatite	6	12	0
East ,, ,,	6	11	0

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S. Wales	3	2	0
Scotland	2	19	0
Cleveland	3	0	0
Cast Iron—			
Midlands	2	15	0
S. Wales	3	2	0
Cleveland	3	12	6
Steel Turnings—			
Cleveland	—		
Midlands	2	0	0
Cast Iron Borings—			
Cleveland	—		
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,, ,, (Marine) ,,	—		
,, ,, (Land), N.E.Coast	11	8	0
,, ,, (Marine) ,,	—		
Angles, Scotland	10	8	0
,, North-East Coast	10	8	0
,, Midlands	10	8	0
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Fishplates	13	10	0
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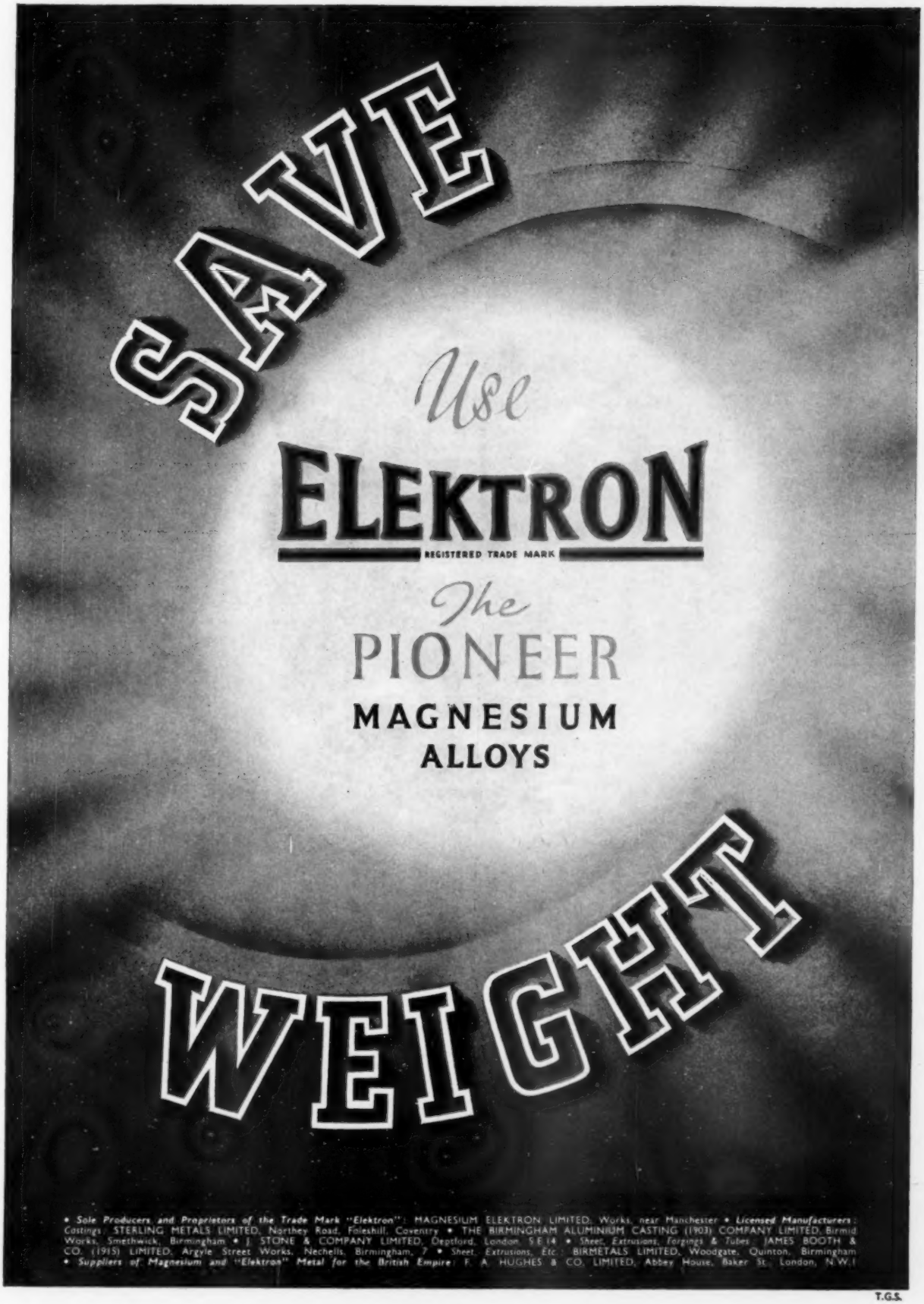
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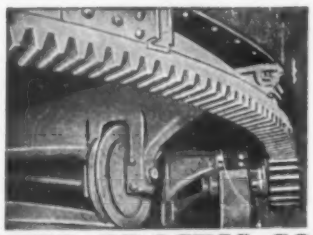

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